A HEYWOOD PUBLICATION

British Chemical Engineering

THE JOURNAL DEVOTED TO THE TECHNIQUES OF CHEMICAL ENGINEERING APPLIED TO INDUSTRY

SEPTEMBER 1957
Vol. 2 No. 9

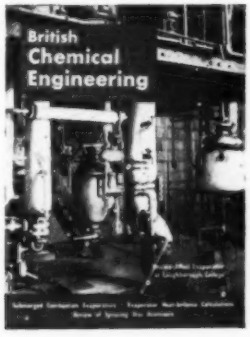
Editor:
J. O. S. MACDONALD,
B.Sc., A.R.I.C., A.M.I.Chem.E.

Assistant Editors:
WILLIAM D. CLIFFORD
G. DILLEY, F.P.S.

Published monthly on the 20th of the preceding month by HEYWOOD & CO. LTD., Drury House, Russell Street, Drury Lane, London, W.C.2

Telephone: Temple Bar 3422

Classified Advertisements and Index to Advertisers appear at the end of the journal



This small-scale Kestner plant includes a climbing-film first effect, a forced-circulation salting-type unit for the second effect, a vapour preheater and a surface condenser. Vacuum is provided by a wet vacuum pump.

CONTENTS

	Page
Digest	**467**
Leader	**473**
Choice of Overall Heat-transfer Coefficients *by K. J. Forker, B.Sc., M.Sc.*	**474**
Evaporator Heat Balance and Material Calculations *by N. J. Hassett, Ph.D., M.I.Chem.E.*	**478**
Some Evaporator Manufacturers and Their Products	**483**
Instrumentation for Multi-effect Evaporators *by M. H. Grimes, B.Sc.*	**484**
Surface Heated Tankers	**489**
Submerged Combustion Evaporators *by J. Austin, B.Sc., M.I.Chem.E.*	**490**
Demineralisation Developments	**494**
British Plastics Convention	**495**
Liquid Atomisation in Chemical Engineering: Part 2—Rotary Atomisers *by R. P. Fraser, O.B.E., M.I.Chem.E., E. P. Eisenklam, Ph.D., M.Eng.Sc., and N. Dombrowski, Ph.D., A.M.I.Chem.E.*	**496**
Index of Nomograms, 1956	**501**
Selection of Cooling Towers and Air-cooled Heat Exchangers *by Edward B. Talbot, B.Sc. (Chem. Eng.), A.C.G.I., and Derek J. Tow, B.Sc. (Eng.), Dipl. Chem. Eng., A.M.I.Mech.E., A.M.I.Chem.E.*	**502**
American Letter	**504**
Nomogram No. 16	**506**
Process Engineer's Notebook	**508**
World of Chemicals	**510**
Book Reviews	**512**
Plant Equipment News	**514**
Month's News in Brief	**522**
People in the News	**524**

BRITISH CHEMICAL ENGINEERING is published monthly by HEYWOOD & CO. LTD., Drury House, Russell Street, Drury Lane, London, W.C.2. Tel.: TEMple 3422. BRITISH CHEMICAL ENGINEERING is available by annual subscription at a price of £1 10s. 0d. sterling for 12 issues post free ($6 U.S.A. and Canada) or, alternatively, by standing order through newsagents at 2s. 6d. per copy net. BRANCH OFFICE: 12 St. Ann's Square, Manchester. Tel.: Deansgate 3277. Entire contents are copyright and must not be reproduced without written permission.

Swartwout AUTRONIC SYSTEMS
are now everywhere

Now being manufactured by Elliott Brothers (London) Ltd. Swartwout Autronic Equipment comprises miniature all-electronic units which completely eliminate transmission lags in indicating, recording and controlling circuits.

Swartwout *Autronic* **CONTROL SYSTEMS**

ELLIOTT

Full details from the Swartwout Division of

ELLIOTT BROTHERS (LONDON) LTD., CENTURY WORKS, LONDON, S.E.13 (TIDEWAY 1271)

BRITISH CHEMICAL ENGINEERING

DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

Evaporation at Low Pressure

IN the past attempts have been made to explain evaporation phenomena at very low pressures by means of the kinetic theory. In practice, however, the rates of evaporation obtained differ from those deduced from the kinetic theory. A sound explanation for these divergencies is that collisions taking place among molecules cause some of them to be returned to the liquid surface. This factor had not been taken into account by the kinetic theory which will then only be valid for cases where the distance between the evaporating and condensing surface is less than the mean free path. In practice the condenser will be situated at a distance many times greater than the latter with the result that molecules are returned to the liquid through collisions. A recent paper (G. Burrows, *Journal of Applied Chemistry*, July, 1957, 375-384) outlines a semi-empirical method of representing the behaviour of low pressure evaporating systems. In the mathematical treatment of the theory a factor called the evaporation efficiency factor is introduced. This is simply the ratio of the actual evaporation rate to the theoretical. From the geometry and construction of an evaporating system it is possible to estimate the value of this factor. The author shows how it is affected by the conditions of evaporation, for example, if the level of liquid in the vessel from which evaporation is taking place falls then the vessel walls will cause some of the evaporated molecules to return to the liquid surface. The value of the efficiency factor will therefore decrease with fall in liquid level. In large evaporating systems where the condenser is at some distance from the evaporating surface and where a condenser and evaporator are infinite parallel planes the factor has a value of 0.5. The author compares values of the evaporation efficiency factor estimated by means of the semi-empirical theory with actual published data for the evaporation of ice and mercury. Good agreement between the author's calculated values and those observed in practice was obtained.

High-Vacuum Insulation

AN example of the use of high vacua for insulating purposes is provided by two recently-designed Dewar vessels for transporting liquid hydrogen. These vessels are 440 and 840 litres capacity respectively and they employ two stages of vacuum insulation. The direct liquid hydrogen container consists of an inner vessel with a first stage of insulation which is completely surrounded by a radiation shield cooled by liquid nitrogen in a secondary tank The whole of this assembly is then mounted inside the second stage of vacuum insulation. It is reported that by the use of this technique thermal radiation is reduced by a factor of at least 200 and becomes of the same order of magnitude as the residual gas conduction or the solid conduction through piping and insulation supports. Tables are available for these vessels, relating evaporation rates to residual gas pressures in the jackets. For example with a residual pressure of 10^{-6}mm. Hg and an outer shell temperature of 52°F. the daily evaporation was 0.8% of the total capacity for the 840 litre vessel. These vessels were really the offshoot of a programme for the design and construction of a large-scale hydrogen liquefier carried out by research workers at the U.S. National Bureau of Standards. The publication of the details of these designs is unusual because we normally look to this source for purely fundamental scientific data. Details are given in Research Paper 2757 (*J. Res. Nat. Bur. Stand.*, Vol 58, No. 5, 1957, p. 243).

Friction in Pipes

THE problem of energy losses caused by the internal roughness of pipes upon fluid flow has been the subject of a number of investigations since the time of Piggott's initial researches and the work of Nikuradse's on artificially roughened pipes* and that of Moody, and others who have all made their important contributions to the subject. The general finding, with which many engineers are familiar, is that in the turbulent region of flow depending upon the relative roughness of a pipe there will be a point at which the friction factor in either the Fanning or Colebrook equations becomes independent of Reynolds number. A recent interesting contribution to this field† has been made by J. K. O'Sullivan of the U.K.A.E.A., Risley, who reports his investigations on the flow of fluids through pipes whose interior surfaces have been disturbed by the drilling of a system of holes. The results do not show any independence of friction factor from Reynolds number but, instead, while greater than the smooth pipe value, it is always a function of the Reynolds number. The effect may be summarised briefly by stating that the smooth pipe friction-factor is increased by a constant multiplying factor at high Reynolds numbers. This multiplying factor depends upon the number of holes, their depth, and probably their pitch. Increase in the hole diameter, for example, produces an increase in the friction factor whereas increase in the depth of the holes causes the friction factor to decrease in value.

* Nikuradse, J. *V.D.I. Forschingsheft.* 1933, 361.
† *Engineering.* 1957, 183, p.684.

Impedance Heating of Pipelines

THE problem of maintaining products of high viscosity in a state sufficiently mobile for pumping can be overcome by a number of methods, the most usual being jacketed or traced pipelines through which steam or some other fluid is passed at elevated temperature. Another more cumbersome method is to thread a smaller pipe carrying the heating medium through the interior of the main pipeline. These methods have a number of disadvantages; there is the risk they incur of overheating the product, especially when a pipeline is being defrozen. This may be a serious objection when waxes tending to polymerise are being handled. Then there is the uneven

distribution of heat along the length of a pipe as well as across its diameter. Finally, there are practical difficulties in making joints between jacketed sections and in the case of traced lines the necessity to carry the tracing tubing across the flanges at joints in the main pipeline. Electrical heating of the pipelines is often a good alternative to the well established methods. By electrical heating is meant not the use of a heating element wrapped around the pipe exterior, for this would be too costly a measure, but the impression of low voltage AC to the wall of the pipe using the conveyed fluid as a current conductor also. This impedance heating method lends itself readily to simple thermostatic control and compared with more conventional methods of pipe heating it distributes the heat more evenly along and across the pipe interior. The system has two characteristics which make it unique for fluid transmission at high temperatures. It does not matter whether the fluid is in motion and therefore dead spaces need not be feared. Again, the entire pipe system can be thawed out after a complete shut down without risk of overheating. An authority on this system of heating (H. S. Bell, *Pet. Ref.*, July, 1957, 175-178) states the capital cost to be lower than that of traced or jacketed lines. Maintenance costs also are very low while for power costs Bell gives a graph from which one can deduce, for example, the loss from a 6-in. pipe carrying a fluid at a temperature of 200°F. above the surroundings to be 3.4 kW.h per hour per 100 ft. length of tubing. One limitation, it cannot be used in the possible presence of explosive gases.

Surface Promotors

TO improve heat-transfer rates in condensers by causing the condensate to form in drops upon the cool surface is the aim of research being carried out by a number of organisations. Most of this work is devoted to the treatment of the condenser surfaces with promoters, materials which being repellent to the condensing medium cause it to form in drops upon the cooled surface. One of the most sought after properties of these promoters is prolonged stability of their films upon metal surfaces. Success in this direction would mean smaller condensers in a number of plants condensing not only steam but other vapours as well. At least two organisations, the D.S.I.R. (M.E.L.R., East Kilbride) and the B.C.U.R.A. are working on this problem and a brief account of progress to date of the work undertaken by the former body is given in the annual report of the Director (Mechanical Engineering Research, 1956, H.M.S.O.). With the help of research workers at Queen Mary College, London, the effectiveness as promoters of some seventy chemicals has been investigated. The minimum life of a promoter film was found to be never less than 500 hours and in one particular case a promoted surface was still producing dropwise condensation even after five months in use. While the work is not yet advanced enough to be applied commercially two trials are reported where dropwise condensation was obtained in full-scale equipment. In one case a marine condenser was used for the experiments and, in the other, a power station condenser. The last example was the less successful of the two because the action of the promoter film was hindered by rust and the effect of air, factors which arose from the intermittent use of the condenser. Although most of the work at Queen Mary College has been concerned with the condensation of steam on treated copper surfaces, efforts are being made to find promoters for the condensation of organic vapours, such as the common refrigerants. The same report gives a brief account of more work on the measurement of heat transfer coefficients of regenerator matrices, on the effect of discontinuities, such as bends and changes of sections upon heat transfer rates in forced convection, and on the effect of introducing air to condensers that are used in the chemical, process and other industries.

Scottish Natural Gas

WITHIN a few weeks the last section of the main which will connect the governor plant of the methane well at Cousland near Edinburgh with the town's-gas plant at Musselburgh will be joined in position and, for the first time in Great Britain, natural gas will be available for supplementing manufactured gas for consumer use. Initially the methane will be used at Musselburgh on an experimental basis and only a small amount will be received from the well. As the gas is "rich" it will be utilised for bringing up to the standard calorific value coal gas of a lower calorific value, and there will be no need at first to reform it. Little is yet known about the reserve of gas in the Cousland anticline (estimates range from 2,000 million cu. ft. to 200,000 cu. ft.), but it is hoped that after a number of months' experimental working a better idea may be gained, and that it may be possible to assess the advisability of installing catalytic reforming plant. In this matter the Scottish Gas Board engineers will have the benefit of experience obtained at Point of Ayr, North Wales, where fire damp from mines is being used as a raw material for the public gas supply. The Cousland natural gas, which, for convenience, is referred to as methane, contains 95-96% of that compound, together with ethane and other hydrocarbons. The well originated from exploration work for oil-bearing strata undertaken by British Petroleum in 1937. It was not worked commercially at that time, but, after the Gas Council had arranged with B.P. in 1954 for further drillings to be undertaken it was decided to make a second well at Cousland. The gas yield was not commercial, but the Scottish Gas Board decided to embark on the present tests using the original well.

Study of Metal Physics

SIR WILLIAM LARKE, immediate past president of the British Welding Research Association, criticised recently the isolation in which research work on fundamental metal physics is being conducted in Britain. If welding were to enjoy the "uninhibited confidence" of engineers, welding research workers and all others concerned in metal physics must co-operate, he said, and he called urgently for the "most influential body in the field" to summon a conference from which would spring the necessary co-ordination of effort in welding research. The potentialities of the present industrial revolution, he asserted, depended largely on the work of the Association, as plant for many new processes was entirely dependent on the availability of efficient welding methods. The Association, therefore, had a high mission and its work needed to be expanded and, indeed, supported by industry more than it was at present. Sir William was speaking on the occasion of the official opening (by Lord Tedder) of the Association's new 14,000 sq. ft. metallurgical laboratory, at Abington Hall, near Cambridge. (See also "People in the News," p. 524.)

Titanium Alloys by Sintering

THE possibility of applying powder-metallurgy processes to the fabrication of tin-titanium-aluminium alloys for plant designed for high temperature working is being investigated at the Tin Research Institute, Greenford.

Middlesex—a body that has just celebrated the twenty-fifth anniversary of its foundation. The conventional method of making titanium alloy parts by arc melting, rolling, and forging, involves waste of valuable metal, and an attempt is being made at Greenford to achieve the same end-product, without waste, by sintering the powdered metallic ingredients. The powders are filled into a mould of the end-product, pressed, and heated to sintering point. The present work, which is being undertaken in the Institute's metallurgical department under the direction of Dr. E. C. Ellwood, includes a study of compacting pressures and sintering temperatures.

Zinc by Blast-Furnace

A PROCESS for the production of zinc by blast-furnace technique has been developed by the Imperial Smelting Corporation, and it is being operated, with two furnaces, at the Corporation's Avonmouth establishment. The total daily production of the metal is at present 70 tons but the furnaces were built essentially as pilot plants, and the economic size of a furnace is known to be considerably larger. Each furnace is charged with coke and sinter-roasted zinc concentrates, and air, preheated in recuperators, is blown through tuyeres at the bottom. The process depends essentially on rapid condensation of the reduced zinc, and, to achieve this, the gases from the furnace, containing 5-6% zinc vapour, are passed to a condenser and are cooled by a shower of molten lead. The lead cooling-medium is circulated at a high rate and is water cooled. By this means the gases leaving the furnace are rapidly chilled to 600°C. and they are further cooled to 450°C. before leaving the condenser. Under favourable conditions about 89% of the zinc vapour entering the condenser is recovered as molten metal. The remaining 11% is recovered as dross and blue powder, which is returned to the furnace charge. The process is not limited to high-grade zinc concentrates but can use materials of high iron content unsuited to retort working or electrolytic zinc production. Mixed lead-zinc concentrates can also be worked in the blast furnace; in this practice the lead is tapped from the furnace hearth as bullion which collects any silver present. The reduction of lead, being exothermic, does not require any extra carbon but results in an increased carbon dioxide content in the exit gas. On a typical furnace, with the charge preheated to 800°C. and with the air blast at 600°C., the carbon consumption may be calculated as the sum of 90% of the weight of zinc to be volatilised and 20% of the weight of slag to be formed. The new process is described in detail by S. W. K. Morgan, research director, Imperial Smelting in the *Bulletin of the Institution of Mining and Metallurgy*, 1957, August, p. 553.

A Market for the Winning

ALTHOUGH so far British petroleum-equipment makers had neglected the Canadian market for easier outlets, and were only supplying a "miserable" 5% of the plant used in Canada, there was a large export market in that Dominion to be obtained for the picking, said Mr. J. M. Storey, leader of a goodwill mission to Canada from the Council of British Manufacturers of Petroleum-Equipment, on the mission's return to Britain recently. Capital expenditure in the Canadian petroleum industry was at the rate of £275 million a year, he said, and this included £101 million on pipeline construction including valves, pumping and boosting stations, and £41 million on refinery construction and bulk storage. This could be supplied from Britain, yet 95- to 98% was purchased from the United States. The Canadians were "embarrassingly keen" to buy from the United Kingdom but their purchasers bought on price, delivery and service. Particularly when the labour content of a plant was high, British prices were better than those of Canadian or United States manufacturers. Britain, however, had to give attention to delivery and service. It was essential, right from the start, to maintain adequate stocks of products and spares, to have representatives in the country who were fully conversant with the products and their use, to provide good sales literature and to deal quickly with all inquiries. The Canadians did much of their business by personal contact and telephone. Mr. Storey regarded the Atlantic ocean as connecting rather than separating Canada and the United Kingdom. Some reorientation of attitude was required, however, for that view to be generally adopted. He suggested a possible increased use of the transatlantic telephone. The mission is to publish soon its report. The story that they bring back is not new, but it is now amplified with their own convincing experiences of the market.

New Coal Tar Processes

WORK by the Coal Tar Research Association on the thermal high-pressure dealkylation of tar oils has reached a point, according to the report of the Department of Scientific and Industrial Research for the year 1955-56, recently published (H.M.S.O., 9s. 6d.), where only the problem of preventing certain catalysts from losing their activity or of regenerating the activity easily bars the opening up of the possibility of converting coke-oven naphthas to pure benzole and toluene. By thermal treatment at 600°C and 1500 lb./sq. in. pressure, alkyl or polyalkyl aromatic hydrocarbons are dealkylated without the formation of appreciable amounts of higher boiling material. With vertical retort oils the reactions are accompanied by complete cracking of the paraffins and they are therefore highly exothermic and difficult to control. A typical coke oven naphtha yielded a product which contained only 3.4% benzene and 10.5% toluene. Certain catalysts have, however, been developed by the Association which enable the five-membered ring in indene or hydrindene to be cleanly split off; by this means a coke-oven naphtha can be converted to a product in 75% yield which consists of a mixture of benzene and toluene and which, moreover, is free from sulphur. So far these catalysts have proved to be short lived. By both the thermal and catalytic process coke oven naphthalene oils can be upgraded, and the naphthalene content of a coke oven drained naphthalene oil was increased from 19.5% to 59.4%. On the fluidised catalytic naphthalene oxidation process the Association has completed the statistical testing of catalysts and an overall equation has been evolved from which the results under any conditions of temperature, air/naphthalene ratio, contact time and catalyst composition can be calculated. Alternatively, the required catalyst composition and reaction conditions to give certain results from a given feedstock can be fixed. It is planned to test the operation of the C.T.R.A. microspherical catalyst in a 2-ft. diameter reactor, and the commercial scale production of the catalyst is now being investigated. Studies on the extraction of tar acids from tar oils by aqueous solutions of pyridine base salts have shown that the process is as successful with a commercial carbolic oil as with a synthetic cresol/naphtha feedstock. Some difficulty has arisen, however, when using the carbolic oil due to the precipitation of aniline sulphate crystals and the removal of traces of neutral oils and tar bases from the recovered tar acids is still not satisfactory.

Continuous Hydro-Refining

PILOT plant for the continuous catalytic hydro-refining of crude benzole, naphthas and other hydrocarbons has been built at the Thorncliffe works, near Sheffield, of Newton Chambers. It will operate a new process which has been elaborated by Coal Tar Research Association and for which Newton Chambers have obtained development rights. Hydrogen or hydrogen-containing gases may be employed in the plant and it is claimed that an almost theoretical yield of refined products is obtained in the hydrogenolysis of sulphur compounds, gum-forming olefins, and colour-forming bodies. The process involves, it is said, a comparatively short contact time, thus allowing a high output. Moreover it operates at relatively low pressures for naphtha refining, and this results in economy in hydrogen consumption and in reduction to a minimum of the conversion of aromatics to naphthenic hydrocarbons. The choice of hydrogenating gas and the general operating conditions best suited for the desulphurisation of a particular feed stock can be ascertained in a small laboratory scale unit. The pilot plant, which is capable of dealing with 500 gallons of feed stock a day, will be used to determine the optimum operating conditions, together with other chemical engineering data for any crude benzoles and naphtha. It is understood that the plant has been designed for wider operating conditions than those required for the hydro-desulphurisation of benzoles and naphthas, and that it can be readily adapted for further investigations and development work.

Prospect for Steel Making

THE Iron and Steel Board have told the Minister of Power, as a result of their most recent survey, that, although there may well be more technical change in the British iron and steel industry during the next 10 or 15 years than there has been during the past half century, none of the many new processes developed throughout the world is likely to cause an early radical change in the industry. Dealing with the increasing use of oxygen in steel making they state that the method of introducing oxygen through the roof of open hearth furnaces developed by the Steel Company of Wales at their Abbey Works has proved so successful that arrangements have been made for its use in America, and that the first oxygen-blown converter in this country will soon be in operation at the Corby Works of Stewarts and Lloyds. (It is understood, as we go to press, that it will in the autumn.) Facilities for oxygen blowing are also being installed at the Ebbw Works of Richard Thomas & Baldwins, and at the new Bessemer shops proposed for the Steel Company of Wales and for Consett Iron. The practice of using oxygen for pre-refining blast furnace metal before it goes to the open hearth furnace is likely to increase but the extent to which it is adopted depends on progress with the more revolutionary changes in steelmaking. Although oxygen has proved its worth as a means of increasing output in conventional plant, there is still some doubt, they point out, as to its effect on the life of furnace linings. Seldom, however, is the life shortened to an extent which cancels the gain in production.

Reprieve for Chemicals?

THE most notable change in the new Labour-Party statement of policy, so far as the chemical industry is concerned, is the absence of specific reference to chemicals in the Party's modified proposals for the acquisition of industry by the State. The new plans are based largely on the emergence in private industry of large firms, about 500 of which (according to a quoted report of the National Institute of Social and Economic Research) account for about half the profits made in Britain and about half of the investments. The influence of the shareholders in these firms, the Party's study group claim, is small and they advance the policy of the State's purchasing industrial shares and providing equity capital. In this way, they say, the fruits of any enterprise will be shared by the community through an extension of public ownership. The most important of the new postwar industries, including oil refining, petro-chemicals, detergents, synthetic textiles, synthetic rubber, and the building of atomic power stations have all been developed, it is argued, by a handful of large and established companies. Examples of "joint enterprise" mentioned are nylon spinning—undertaken jointly by I.C.I. and Courtaulds; British Petroleum Chemicals—sponsored by the B.P. and Distillers; and the building of atomic power stations, necessitating the formation of groups of large companies. The drafters of the statement wisely, do not wish to subject such firms to detailed supervision, and they concede that the great majority of them are serving the nation well. Nevertheless the document holds out for them the ill-defined prospect of a review of the Companies Acts, because of the "community's entitlement" to satisfy itself that the "powerful" boards act in conformity with the needs of the nation. The statement is to be submitted for ratification to the Party's conference.

Nuclear Patent Agreement

PHILIPS ELECTRICAL and the U.K. Atomic Energy Authority have settled amicably an action arising out of the late Professor Fermi's nuclear energy patent, which is based on the discovery that he and his collaborators made in Rome in 1934, that neutrons slowed down by collisions with light atoms are more effective than fast neutrons in producing radioactive elements. The settlement involves the withdrawing of a petition by Philips for the renewal of the patent. The opponents of the petition, who included the English Electric Co. and G.E.C.; A.E.I. John Thompson Nuclear Energy Co.; C. A. Parsons, the Central Electricity Authority and the U.K.A.E.A., have stated in the High Court their agreement to the dismissal of the petition.

The basic Italian patent was applied for in 1934. Full title and all rights to the invention for most countries other than the U.S.A. were subsequently acquired by Philips, and the registered owners of the U.K. patent (465,045) are Philips Electrical. Since 1948 there have been discussions between the patentees and the A.E.R.E., but as no agreement resulted, the patentees caused a writ to be served on the U.K.A.E.A. in March, 1956 alleging infringement of the patent. In April, 1956 the patentees also petitioned for extension of the term of the patent. As the parties felt, however, that it was preferable to settle the matter amicably a compromise has been agreed. In a joint statement, the parties say that the Authority has been conscious of the great contribution made to the advance of nuclear science by Professor Fermi's "remarkable" discovery, and of the valuable development work in the nuclear field carried out by Philips in conjunction with the A.E.R.E. Philips, for its part, has been anxious to avoid causing interference with the development of nuclear energy projects in the United Kingdom. In addition to withdrawing the petition, Philips are undertaking to secure that no claims will be made for the infringement of any corresponding patents abroad owned or controlled by any associated company of Philips in respect of articles and materials exported by the Authority or any of the companies engaged in association with the Authority in the nuclear power programme. In return for these concessions the Authority is paying a sum to Philips.

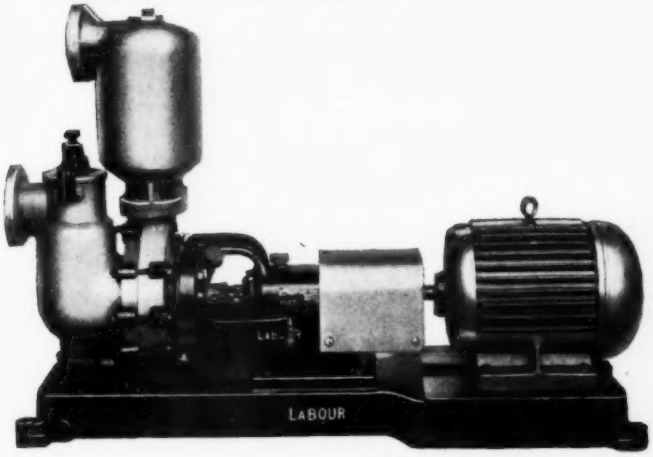
DEGREES BE

10° 18° 25° 32° 41° 45·6° 55° 61° 65°

·00150
·00145
·00140
·00135
·00130
·00125
·00120
·00115
·00110
·00105
·00100
·00095
·00090
·00085
·00080
·00075
·00070
·00065
·00060
·00055
·00050
·00045
·00040
·00035
·00030
·00025
·00020
·00015
·00010
·00005

INCHES PENETRATION PER MONTH

LABour Pumps for Chemical and allied industries have been designed specifically for such purposes, and are made from alloys especially developed to provide the highest resistance to corrosion.



BRONZE (88% CU–10% SN–2% PB)
CAST IRON
K 26
LEAD
'MONEL'
R–55

LOSSES BELOW THIS LINE ARE CLASSED "FULLY RESISTANT"

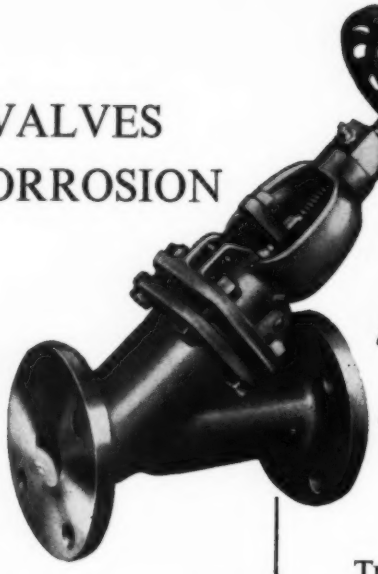
0 10 20 30 40 50 60 70 80 90 100

% H_2SO_4

LABOUR PUMPS

BRITISH LABOUR PUMP CO LTD. BLUNDELL ST LONDON N7 Tel: North 6601-4

A RANGE OF VALVES THAT DEFY CORROSION



NOW includes

THE Y VALVE

GATE VALVES
Available in sizes from ½" to 10" bore. All valves are flanged to British Standard sizes.

TANK VALVES
Disc rising or lowering bottom outlet valves for tanks and reaction vessels.

REMOTE CONTROL VALVES
Disc rising or lowering tank valves with right-angled control for inaccessible outlets.

THE STANDARD RANGE of APV-Cooper Stainless Steel Valves has now been extended to include Y Valves in sizes from ¾-inch to 6-inch bore.

These valves, in common with the split-wedge gate and tank valves supplied in thousands by APV to the chemical and allied industries, are precision built and robustly constructed in stainless steels to suit most corrosive conditions.

Incorporating many outstanding design features, APV-Cooper Valves afford smooth, positive control of liquids or gases at pressures up to 150 p.s.i.—and they are produced by Britain's largest manufacturers of equipment in the corrosion-resistant metals. APV

APV-COOPER *STAINLESS STEEL VALVES*

THE A.P.V. COMPANY LIMITED, MANOR ROYAL, CRAWLEY, SUSSEX. TELEPHONE: CRAWLEY 1360.

A HEYWOOD PUBLICATION
British Chemical Engineering

The Versatile Evaporator

EVAPORATION is a process that has played an important part in man's existence since the time when salt was made by solar evaporation. Many consumer goods, whether they come from chemical or other processing industries, either depend upon or owe some important property to this process. Sugar, common salt, artificial fibres, paper, evaporated milk, coffee essence and fruit juices are but a few of the many materials which require evaporation at some point in their manufacture. Such useful chemicals as caustic soda and glycerine rely upon it, and it plays a significant part in the generation of power and in refrigeration.

One of the earliest evaporators was the direct-fired open pan, which was widely used in the Middle Ages for salt-making, and as recently as the mid-nineteenth century the juice from sugar cane or beet extraction was concentrated in equipment of this kind.

The industrial revolution, especially during its later stages, witnessed a number of revolutionary changes in evaporating equipment. First came Howard's introduction of the vacuum pan to the sugar industry, to be followed by the multiple-effect system of evaporation of Rilleux. His aim was to devise a method of sugar manufacture in which, at individual factories, the combustion of cane waste would provide all the steam and power necessary, and this was accomplished by re-using the latent heat of steam for successive evaporations, an invention ranking with the separate condenser of James Watt.

The practice of evaporation was well established by the time it became one of the unit operations in the early days of chemical engineering, and although the unit operation concept in chemical engineering will eventually be discarded, it is difficult to see how, in the light of the present state of our knowledge, a transition to a broader and more fundamental status can occur. The design of many varieties of evaporator is still more of an art than a science. The all-important overall heat-transfer coefficient, for example, is virtually impossible to estimate for the majority of evaporators. While relationships exist which give values of the right order of magnitude for this entity, previous experience and pilot-scale tests are the only means for obtaining reliable design coefficients.

Certainly, when it comes to useful design material, the literature of chemical engineering is far from prolific. Here and there are accounts of heat and material balance calculations for multiple-effect evaporators, but their weak point is always the overall heat-transfer coefficients they assume.

The heat-transfer side of evaporation is a major problem, for not only is the underlying phenomenon of heat transfer to boiling liquids a complex one, but there is a host of additional complicating factors such as difference in rates of circulation, steam distribution and scale formation. It is no wonder, therefore, that eminent researchers of the calibre of Kirschbaum, Bonilla, Jakob and many others have been thwarted in their various efforts to describe this process quantitatively. Very often they have not had that exchange of experience which other researchers enjoyed and which their own efforts deserved.

We recall a paper given some years ago to the Institution of Chemical Engineers in this country on the subject of heat transfer in climbing-film evaporators; this was one of the first papers of its kind to be given on this particular subject. The authors, who used a small-scale evaporator employing tubes of diameter much smaller than customary in industrial practice, were able to show that in their apparatus the boiling film coefficients were proportional to power functions of viscosity feed rate and temperature. When papers like this are given, the discussion often broadens the original conclusions, but on this occasion not only were no useful experiences forthcoming—despite the many climbing-film evaporators in operation—but the original conclusions were considered to be inapplicable to full-scale evaporators of this type.

While more information on heat transfer in commercial evaporators would be invaluable for improving our understanding of evaporation, evidently a great deal more fundamental work on such phenomena as two-phase flow in tubes, slippage of vapour and liquids and rate of scale build-up is also required.

The difficult heat-transfer angle which accompanies evaporation processes is not the only factor delaying the development of this unit operation. Unlike such unit operations as distillation, extraction and heat transfer in general, with evaporation there is not the same kind of commercial demand, in spite of numerous opportunities for new applications. Whether nowadays the incentive to make designs more economical is of the same order as it was in Rilleux's day is doubtful. For one thing, tasks comparable to that which he fulfilled with his multiple-effect designs occur but seldom and the advances made in recent years, such as vapour recompression, have left little room for bringing about improvements in heat economy. Moreover, in the industries where evaporation is most widely used, the cost of steam is often the major part of the cost of the product; consequently, the desire for cheaper designs is not a powerful one.

Nevertheless, from the time that it first attracted the attention of chemical engineers, evaporator design has witnessed many detailed improvements, apart from vapour recompression and heat pump designs for low-temperature evaporations. A sure sign of advance is the wide range of liquids, some of them distinctly difficult to handle, that can now be concentrated with success. To the early designs of climbing- and falling-film and natural-circulating types have been added a number of other constructions. Among these are the wiped-film, infra-red, carbon block and submerged combustion evaporators, as well as a variety of forced-circulation types. The submerged combustion evaporator owed much to the pioneer work of Norman Swindin, and it is thanks to his efforts and those of R. P. Fraser that this country had a distinct lead in oil-fired submerged combustion evaporators. Finally, the operation of evaporators, especially the control of liquor level, has been advanced considerably through the use of the techniques of automatic process control.

CHOICE OF OVERALL HEAT-TRANSFER COEFFICIENTS IN EVAPORATORS

by K. G. FORKER*
B.Sc., M.Sc.

This article illustrates a few of the steps that must be carefully considered before the design value of the overall coefficent of heat transfer is chosen

IN spite of many attempts aimed at computing heat-transfer coefficients (H.T.C.s) for evaporators, the commercial company engaged in quoting evaporating plant is, to a large extent, forced to rely on its past experience when putting forward a quotation. This experience includes information obtained from its other plants, pilot-plant test runs, competitors' plants and such further particulars as are necessary from its own or its customer's laboratory tests on the liquid to be evaporated.

The overall coefficient that will be discussed in this article is given by the general equation:

$$Q = U\ A\ \triangle t \qquad \ldots . (1)$$

where Q = heat transferred across the heating surface, Btu/hr;
A = heating surface area, sq. ft;
$\triangle t$ = the actual temperature difference between the temperature of the heating element (usually condensing steam) and the temperature of the boiling liquid, °F; and
U = the overall coefficient of heat transfer, Btu/hr ft² °F.

It should be noted that what is sometimes termed the apparent overall coefficient is given by the equation:

$$Q = U_A\ A\ \triangle t_A \qquad \ldots . (2)$$

where U_A = the apparent overall coefficient of heat transfer, Btu/hr ft² °F; and
$\triangle t_A$ = the difference in temperature between the heating element (usually condensing steam) and the assumed saturated vapour above the liquid boiling in the evaporator, °F.

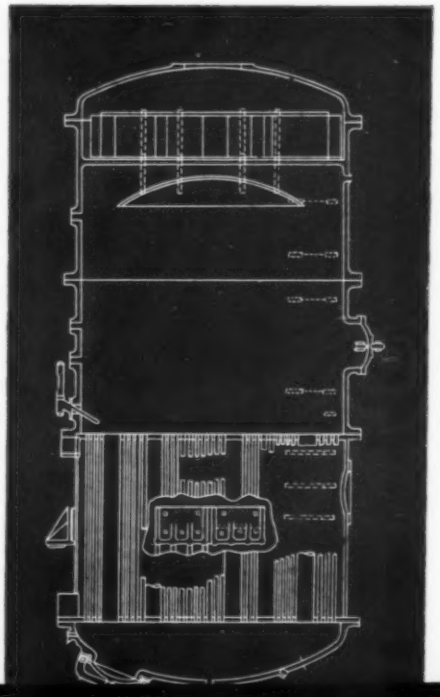
H.T.C.s in Natural Circulation and L.T.V.† Evaporators

Many authors have tried to solve the complex equations governing the rise of a boiling slug of liquid through a steam-heated tube and, at the date of writing, it is fair to state that none of them has completely succeeded in deriving an equation useful in commercial design work. W. L. Badger and his associates[1] have published several papers aimed at finding an empirical equation, and more recently J. M. Coulson and his associates[2,3] have quoted results obtained on a model evaporator. These latter should be treated with reserve as, in the text, certain mathematical errors appear which render the final equation suspect. The authors state that they intend to publish how they derived this equation, when this point should become clearer.

The designer is therefore left with no alternative but to run full-scale tests or to use data gathered from plants already in operation. Obviously, this latter method is by far the cheapest and usually the most convenient. One major problem is that it is often not stated in the literature available under exactly what circumstances the overall coefficient has been determined. Where this is not stated the result should be treated with considerable caution.

Thus, if a short tube vertical (S.T.V.) natural-circulation evaporator of the "Scott" multiple-downtake type as shown in Fig. 1 is being examined for suitability for a particular

Fig. 1. The Scott multiple-downtake natural-circulation evaporator



† *Long tube vertical.*

* **Mr. Forker** graduated in July, 1953, from Durham University with a B.Sc. in chemistry and physics and an M.Sc. in chemical engineering. After two years' National Service in the R.E.M.E., he joined George Scott & Son (London) Ltd. as a chemical engineer specialising mainly on evaporators.

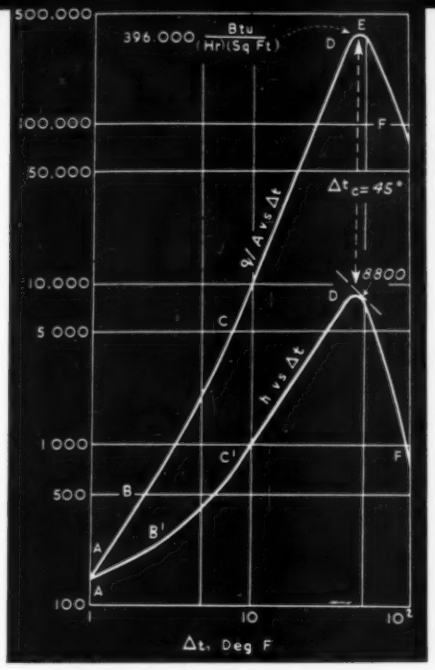


Fig. 2. Water boiling at 1 atm. outside a horizontal, submerged tube.

duty, and the available data on previous test runs are examined, it is usually found that the overall heat-transfer coefficient can vary between 30-350 Btu/hr ft² °F. This means that since the heating surface will be directly proportional to the overall coefficient, other things being equal, a more accurate assessment of how to achieve the highest heat transfer is required.

The value of the heat-transfer coefficient is due to several factors, among which can be listed:

(1) the liquid level in the pan;
(2) the viscosity and density of the boiling liquor;
(3) the overall temperature difference, $\triangle t$; and
(4) the state of cleanliness of the plant.

It has long been known that, in general, a liquid level one-third the height of the tubes measured from the bottom tubeplate is about the optimum position for the greatest heat-transfer coefficient, although in the S.T.V. designs the operators are usually found to be running with the top tubeplate submerged. Unless there is some other reason, such as scale prevention, this mode of operation is indefensible and it is usually recommended that the pans be run so that the top tubeplate of the calandria, as the heating surface is called, is completely wetted by the liquid spurting from the tubes.

It is a widely held fallacy that if the steam pressure in a multiple-effect evaporator is increased in the first-effect calandria and the vacuum in the last effect is also increased, more evaporation will be bound to occur, since the temperature drop across the total set of effects will have increased. That this is not, in fact, the case is instanced in many reported examples.

One recent U.S. Patent,[4] concerned with multiple-effect evaporation of waste distillery slop, cites an example of how by reducing the steam pressure in the first effect and lowering the vacuum in the final effect, it induced a 20% greater throughput. This is, on the face of it, an anomalous result, but it can be explained by the fact that the rise in the temperature of the liquid in the final pan increased its mobility and hence it moved more quickly over the heating surface, with a corresponding increase in the H.T.C.

Fig. 2 shows heat flux plotted against temperature difference for water boiling at 1 atmosphere outside a horizontal, submerged tube. It can be easily seen that there is a distinct maximum flux at a temperature of 45°F and a quick fall-off above this value, owing to the presence of an insulating layer of steam formed between the liquid and the hot tube surface.

A typical series of test results on three types of paper mill black liquor is quoted in Table 1 (see page 477).

H.T.C.s in Film-type Evaporators

By film-type evaporators the author means the natural falling-film type as shown in Fig. 3 and the wiped-film type as shown in Fig. 4. As far as the natural falling-film evaporator is concerned, it is usually designed to operate so that the modified Reynolds number $4\,\Gamma/\mu$ exceeds 2000.

where Γ = liquor flow in lb./hr per linear ft of wetted tube perimeter; and
μ = the viscosity of liquid in lb./ft hr.

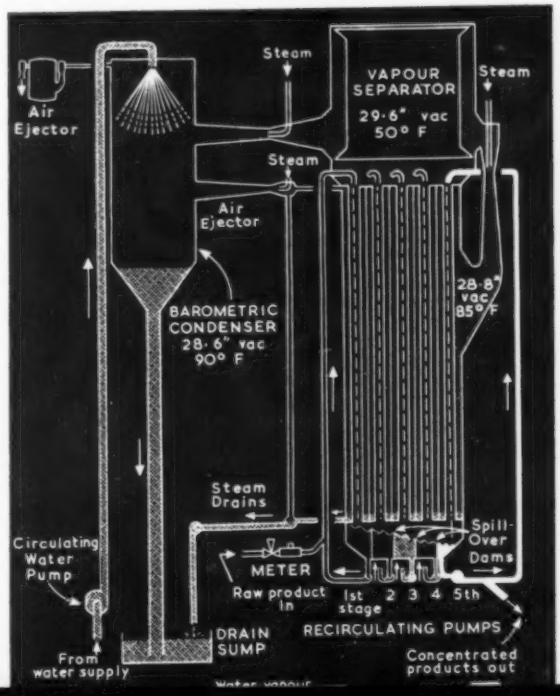
Again, the heat-transfer coefficient chosen is largely a matter of actual test data.

The wiped-film type of evaporator is illustrated in Fig. 4, which shows a cross-sectional view through the body. This unit usually consists of a vertical cylindrical-jacketed section, inside which a flat-bladed agitator runs with a clearance of approximately $\frac{1}{32}$ in. from the wall. Feed enters at the top of this section and flows down the inside of the wall, being wiped by the wipers which are reported to be designed for 44 ft/sec. linear velocity. Above this speed there appears to be little increase in heat-transfer coefficient. The variation in overall heat-transfer coefficient plotted against the arithmetic viscosities of feed and product liquors is shown in Fig. 5.

Forced-circulation Evaporators

It is only for the forced-circulation design, as illustrated in Figs. 6, 7 and 8, that the designer has got a fairly solid foundation of theory on which to base his design. The principle of operation of the evaporators in Figs. 6 and 7 are at once apparent by examining the diagrams. Fig. 8, however, the Scott type of forced-circulation unit, or superimposed calandria as it is sometimes termed, needs a little explanation. It operates on the principle of a centrifugal impeller mounted under the eye of a shroud placed below the bottom tubeplate of the calandria. The pan is filled

Fig. 3. The Skinner falling-film jet recompression evaporator.



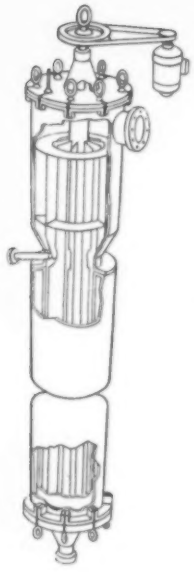


Fig. 4. A cutaway diagram of the Luwa falling, wiped-film evaporator showing details of drive and rotor.

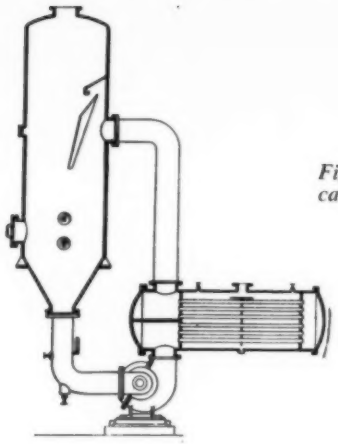


Fig. 7. The Buflovak calandria forced-circulation evaporator.

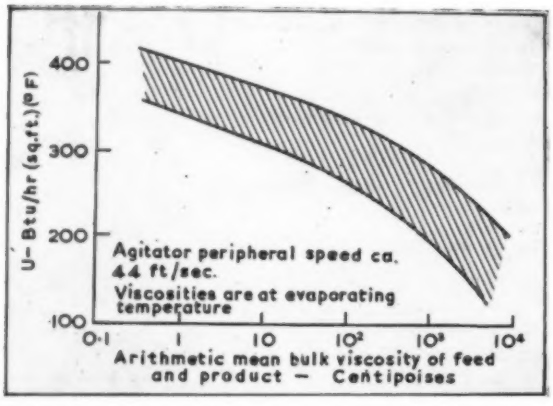


Fig. 5. Viscosity v. U-Newtonian aqueous solutions.

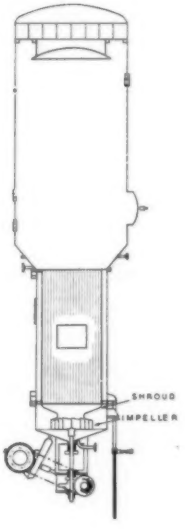


Fig. 8. The Scott superimposed calandria forced-circulation evaporator. Note the position of the impeller in the eye of the shroud.

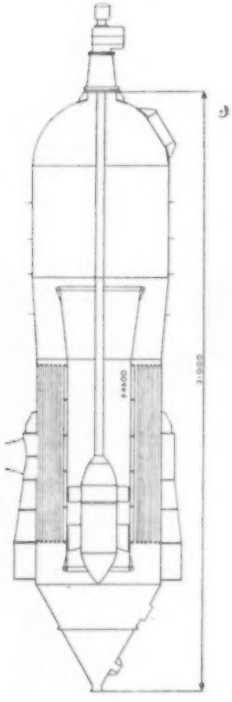


Fig. 6. The Escher Wyss forced-circulation salt pan. Note the axially mounted impeller driven from the top-mounted motor.

above the top tubeplate and the liquid is drawn down the central bundle of tubes and forced by the impeller up the sides of the bottom bowl and into the uptake tubes. In practice, 4-6 ft/sec. is the design velocity and a high-capacity low-head circulator revolving at around 270 rpm is usually employed. The unit has found many applications, being used for such duties as glycerine and caustic soda evaporators.

It is claimed that this type of forced circulation results in a lower horse-power being required than for the more conventional centrifugal pump type as illustrated in Fig. 7, owing to the external pipework between the centrifugal pump and the heater being entirely eliminated.

It has been found that for turbulent flow, that is, when liquid flowing in the tubes has a Reynolds number greater than 10,000, where the Reynolds number is defined as

$$Re = \frac{Dv\rho}{\mu}$$

D = internal tube diameter, ft;
v = velocity of liquid, ft/sec.;
ρ = density of liquid, lb./cu. ft; and
μ = viscosity of liquid, lb./ft sec.;

then the well known Dietus-Boltus equation can be applied to obtain h_i, the heat-transfer coefficient from the wall of the tube to the liquid.

The equation is:

$$\frac{h_i D}{k} = 0.023\ (Re)^{0.8}\ (Pr)^{0.4} \qquad \ldots . (3)$$

TABLE 1—Typical Series of Test Results on Three Types of Paper Mill Black Liquor

Liquid being evaporated	Liquid temperature, °F	Overall heat-transfer coefficient (corrected for boiling-point rise), Btu/hr ft² °F	$\triangle t$, °F	Description of plant
Soda paper mill black liquor				
58.0% T.S.*	224.5	155.1	24	Short tube vertical natural - circulation evaporator of the Scott multiple-downtake type. Tubes 2 in. o.d., 14 G, 6 ft long.[5]
16.3% T.S.	193	124.7	29	
20.8% T.S.	167	163.3	18	
30.0% T.S.	122	137.1	23	
Sulphite black liquor				
48.0% T.S.	236	156	31	As above[6]
32.3% T.S.	199	160.9	27	
20.2% T.S.	167	151.9	25	
26.0% T.S.	130	116.5	37	
Sulphate black liquor ...	261†	165†	21†	†Long-tube vertical evaporator, 2 - in. o.d. tubes 24 ft long.[7]
	237	273	12	
	214	213	12	
	191	235	14	
	168	145	14	
	125	97.5	31	

** Total solids*

where P_r = the Prandtl number = $\frac{c\mu}{k}$

c = specific heat; and

k = thermal conductivity of the liquid.

Hence, by careful measurements of the liquid that is to be evaporated a forced-circulation unit can be proposed.

Recourse has either to be made to the literature or to actual repeated laboratory tests on the liquid to be evaporated to obtain the necessary design data. For example, in a recent forced-circulation design with which the author was concerned the client provided the necessary data on salt solubility as against temperature and a Duhring plot of the liquor boiling points. The liquid being evaporated was a complex mixture of NaOH and KOH with traces of Na_2SO_4 and a little dissolved organic acid. For the values of the thermal conductivity it was decided to use a nomogram that recently appeared in the literature,[8] and viscosity figures for caustic soda were applied.

It is usually found that the most economical velocity of liquid through the tubes ranges from 4-7 ft/sec. and it has been found that boiling does not occur in tubes above about 5 ft/sec., probably owing to the rapid removal of steam bubbles forming at the wall in the stationary film. The basic idea behind a forced-circulation design is to superheat the liquid passing through the tubes and allow it to flash off into a vapour separator before being returned, via the pump, to the heater.

Having computed the value of h_i for the liquor passing through the tube and calculated the outside coefficient of heat transfer of the steam condensing on the tubes by one of the well-known methods,[9] and the overall log mean temperature difference and the resistance to heat transfer of the wall, usually negligible, the overall heat-transfer coefficient can be calculated for the equipment.

It is sometimes advisable to make an allowance for a fouling factor as it is usually called, i.e., to allow for possible scale formation. This is entirely dependent upon the liquid being handled and for a self-cleaning liquid, for example, caustic soda, this can be ignored.

The overall coefficient of heat transfer will be given by Equation (4); the tube curvature being ignored.

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_s} + \frac{t_w}{k_w} + \frac{1}{h_f} \quad \ldots.(4)$$

h_s = steam side coefficient, Btu/ft² hr °F;

t_w = thickness of the wall, ft;

k_w = the thermal conductivity of the wall, Btu/ft² °F hr/ft; and

$\frac{1}{h_f}$ = the fouling factor.

A typical value of the fouling factor is 0.001.

Conclusion

The factors affecting the choice of overall heat-transfer coefficient have been briefly reviewed for the types of evaporator most commonly met with in the chemical industry. Although considerable practical data exist, to a large extent these are kept in the private files of companies actively engaged in the design of evaporator plant and no reliable practical correlation is available. For this reason equipment manufacturers are in a position to give reliable advice on the solution of an evaporator problem and give guarantees based on the data available to them.

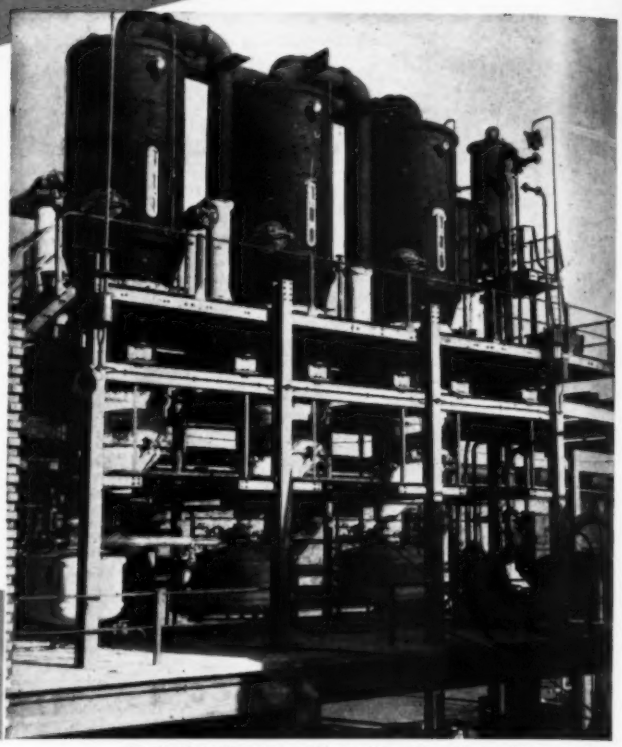
The author wishes to thank George Scott & Son (London) Ltd. for permission to publish the results shown in Table 1 and the drawings in Figs. 1 and 8. Fig. 2 was reproduced from Heat Transmission *by W. H. McAdams, copyright* 1942, *by permission of McGraw-Hill Book Co. Inc.; Figs. 3 and 5 from an article by Lindsay, published in* Chemical Engineering, *April* 1953; *Fig. 4 from a paper by W. Hauschild, published in* Flussiges Obst, 1956. *Heft 6; Fig. 6 from the Escher Wyss Catalogue No.* 25019 (e); *and Fig. 7 by permission of the Buflovak Equipment Division of Blaw Knox Co., from Catalogue No.* 372.

REFERENCES

1. Badger, W. L., *et al. Chem. Met. Eng.*, **46**, 1939, 640; *Chem. Eng.*, **61**, (2), 1954, 183; *Trans. Amer. Inst. Chem. Eng.*, **33**, 1937, 392; ibid., **35**, 1939, 17; ibid., **36**, 1940, 759.
2. Coulson, J. M., and Metha, R. R., *Trans. Inst. Chem. Eng.*, **31**, 1953, 203.
3. Coulson, J. M., and McNelley, M. J., *Trans. Inst. Chem. Eng.*, **34**, 1956, 247.
4. U.S. Patent No. 2,510,233, June 6, 1950.
5. George Scott & Son (London) Ltd.—test data.
6. George Scott & Son (London) Ltd.—test data.
7. Sawyer, *et al. Ind. Eng. Chem.*, **42**, 1950, 761.
8. "The Industrial Chemist", April, 1956.
9. McAdams, W. H., "Heat Transmission", second edition. McGraw-Hill. Page 269.

EVAPORATOR HEAT BALANCE AND MATERIAL CALCULATIONS

by N. J. HASSETT, Ph.D., M.I.Chem.E.*



Triple-effect Evaporator (Photo: Geo. Scott & Son (London) Ltd.).

A complex multiple-effect evaporator system is shown to function as a number of superimposed ideal evaporation sequences. This method enables an accurate analysis of a complex system to be made in a succinct manner.

THE method described of evaluating multiple-effect evaporator systems is of general application, and is particularly useful for the rapid evaluation of proposed modifications to existing exaporator circuits. A full theoretical derivation has been given elsewhere.[1] The present paper gives an alternative derivation in abbreviated form, and deals more particularly with the calculation of secondary heat values and systems with large boiling-point elevations.

The classical or "accurate" method involving a relaxation procedure is lengthy and time-consuming. Short-cut methods are either approximate, limited in application, or both. The present method resolves the balances used in the standard method to four equations which apply to any system and cover its complete analysis. The derivation is rigorous. Heat losses, being small and indeterminate, are more conveniently allowed for in the final figures, but, if known, they can be readily included in the secondary heat values as defined below.

The Derivation

(*i*) *"Ideal Evaporation" and "Evaporative Ratio"*

In an evaporation stage denoted by subscript x, a quantity, E_{x-1} lb., of vapour coming from the previous effect ideally evaporates a quantity, E_x lb., of water from a solution, in accordance with the defining equation:

$$\text{Ideal evaporation} = E_{x-1}(L'_x/L_x) = r_x.E_{x-1}$$

where L'_x = latent heat of condensation of the vapour (steam) at the pressure on the condensing side (steam side);

L_x = latent heat of evaporation of water at the pressure on the evaporation side (liquor side); and

r_x = "evaporation ratio" in the effect. The latent heat of steam increases as pressure decreases, so that r_x will always be slightly less than unity.

(*ii*) *Secondary Heats and "Equivalent Secondary Steam Inputs"*

In practice, the actual evaporation will differ from the ideal evaporation because of one or more secondary heat effects as tabulated below.

Steam Side (Reference temperature: T'_x)	*Liquor Side* (Reference temperature: T_x)
Superheat in steam,	Temperature equalisation of incoming liquor,
Flash heat from earlier condensates,	Heat of concentration,
Intereffect steam bleed.	Superheats.

Secondary heats are regarded as positive when contributing to the evaporation. Denoting the net secondary heat input on the steam side by h'_x (Btu) and that on the liquor side by h_x, the actual evaporation E_x (lb.) in an effect is given by:

$$E_x = (E_{x-1}.L'_x + h'_x + h_x)/L_x$$

$$= \left(E_{x-1} + \frac{(h'_x + h_x)}{L'_x}\right)(L'_x/L_x)$$

$$= (E_{x-1} + S_x)r_x \qquad \ldots.(1)$$

where $S_x = (h'_x + h_x)/L'_x$ $\qquad \ldots.(1a)$

= "equivalent secondary steam" input to effect x.

(*iii*) *Evaporation Sequences*

A quantity of steam, S, fed to a multiple-effect evaporator ideally generates steam (evaporates water) according to the following sequence.

* *Chemical Engineering Department, Loughborough College of Advanced Technology.*

First effect: $r_1.S$.
Second effect: $r_1.r_2.S$.
Third effect: $r_1.r_2.r_3.S$, and likewise.

Adding for the complete series of n effects gives the total primary evaporation, E_S.

$$E_S = S(r_1+r_1.r_2+r_1.r_2.r_3+ \ldots.) = c_1.S.$$

The equivalent secondary steam input, S_1, to the first effect gives rise to a similar sequence of ideal evaporations.

$$E_{S1} = S_1\ (r_1+r_1.r_2+r_1.r_2.r_3+ \ldots) = c_1.S_1.$$

The equivalent secondary steam input, S_2, to the second effect gives rise to a sequence of evaporations starting at the second effect.

$$E_{S2} = S_2\ (r_2+r_2.r_3+r_2.r_3.r_4+ \ldots) = c_2.S_2.$$

Likewise for the secondary steam inputs to the succeeding effects, and summing all the evaporation sequences gives the total evaporation E.

$$E = c_1.S + c_1.S_1 + c_2.S_2 + c_3.S_3 + \ldots + c_n.S_n \qquad \ldots.(2)$$

whence, rearranging;

$$S = \frac{1}{c_1}\ (E - c_1.S_1 - c_2.S_2 - c_3.S_3 - \ldots. - c_n.S_n) \qquad \ldots.(3)$$

The multiplier, c_x, is defined by the above equations and it may be noted that r_x, the evaporative ratio in an effect, will usually lie between 0.965 and 0.99, and for approximative work may be taken as 0.98. The c_x values will, therefore, not be far removed from equivalent whole number terms and, since the secondary steam quantities will be substantially smaller than S, Equations (2) and (3) can be written in approximative form, thus:

$$S = \frac{E}{c_1} - S_1 - \frac{n-1}{n}\,S_2 - \frac{n-2}{n}\,S_3 - \ldots. - \frac{S_n}{n} \qquad \ldots.(3a)$$

Equation (2) also derives from Equation (1), building in sequence from the first effect, bearing in mind that $E_0 = S$.

(iv) Transfer Heats, q_x

The heat transferred across the heating area of the first effect, using saturated steam, is $q_1 = S.L'_1$ (Btu). The heats transferred in succeeding effects are given by the general equation:

$$q_x = q_{x-1} + h_{x-1} + h'_x \qquad \ldots.(4)$$

(v) Temperature Distribution

The total available temperature drop, i.e., the overall temperature drop less boiling-point elevations, divides itself among the effects in accordance with the heat-transfer coefficients and heating areas, the link up with the transfer heats following from the general equation.

$$\theta_x = \frac{q_x}{U_x.A_x} = \frac{q_x}{(U_x.a_x)A_o} \qquad \ldots.(5)$$

where θ_x = driving temperature difference in effect x;
U_x = heat-transfer coefficient in effect x;
A_x = the heating area in effect x;
A_0 = a common reference area, employed if the heating areas are not all equal; and
a_x = the corresponding multiplier for effect x.

Dividing Equation (5) by the sum of such equations for the whole system eliminates the common area, and gives the temperature drop in each effect.

$$\frac{\theta_x}{\theta} = (q_x/[U_x.a_x])/\Sigma(q_x/[U_x.a_x]) \qquad \ldots.(5a)$$

where $\theta = \Sigma\theta_x$ = total available temperature drop.

(vi) Heating Areas

The individual temperature differences are first found from Equation (5a). Substituting in Equation (5) gives a single value for each heating area, or a single common value if the areas are given as equal.

(vii) Intereffect Steam Bleed

In the derivation, the whole of the evaporation from each effect is considered as feeding to the next effect, irrespective of whether, in fact, this quantity is reduced by vapour offtake. The latter is taken care of by including it in the corresponding h'_x value, giving it, of course, a negative sign.

(viii)

The derivation is independent of flow direction and is, therefore, of general application. Effects are numbered in direction of steam flow. The only point to note is that secondary heat values on the liquor side are tied up with liquor flow and in this respect a working diagram is often useful.

(ix) Modifications to Existing Systems

For moderate changes to an existing system, the c_x values will not change appreciably, and the following in-

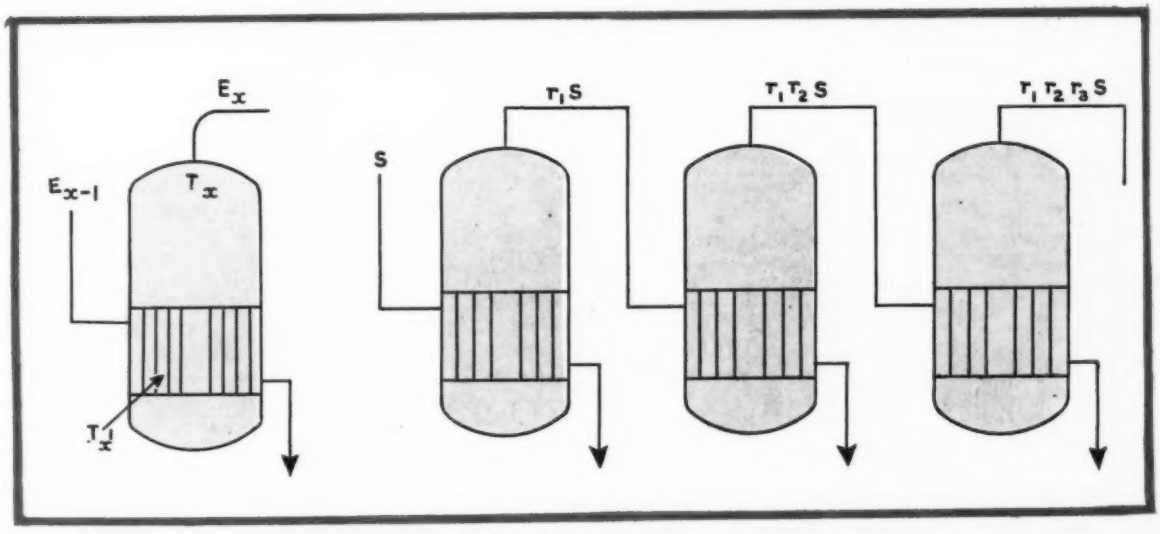


Fig. 1 (left). Diagram representing an evaporation stage. Fig 2 (right). Diagram illustrating the steam generation at each effect of a multiple-effect evaporator.

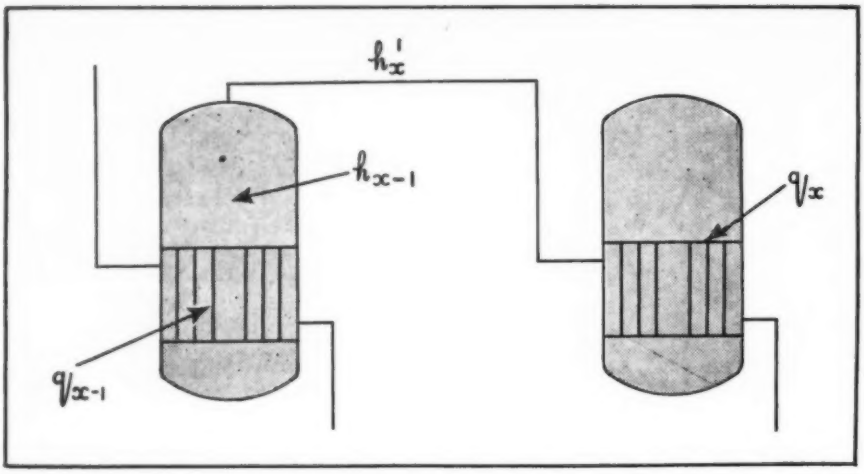


Fig. 3. Diagram denoting the heats transferred in succeeding stages.

cremental form of Equation (3) can be used.

$$\Delta S = \frac{1}{c_1}(\Delta E - c_1 \Delta S_1 - c_2 \Delta S_2 - \ldots - c_n \Delta S_n) \ldots . (3b)$$

Evaluation of Secondary Heat Quantities

As defined earlier, the secondary heat quantities are those quantities of heat, other than the latent heats concerned in the ideal evaporations, which affect the amount of evaporation. They will now be considered individually.

Steam Side

(*a*) *Superheat in Steam.* Unless the steam entering an effect has more than 10°F of superheat, this item can safely be neglected. The value in Btu is given by:

$$0.46\ E_{x-1}\ (T_{x-1} - T'_x) = 0.46\ E_{x-1}\ (bpe)_{x-1}$$

It will be seen that 20°F of superheat is only equivalent to 1% of the total available heat in the steam.

(*b*) *Condensate Pass-on.* Condensate brought in from the preceding effect will give flash heat equal to:

$$C_{x-1}\ (T'_{x-1} - T'_x)$$

where C_{x-1} is the weight in lb. of the accumulated condensates leaving the preceding effect.

(*c*) *Intereffect Steam Bleed.* The equivalent heat value in Btu of a steam bleed between effects $x - 1$ and x is given by:

$$B\ (L'_x + 0.46\ [T_{x-1} - T'_x])$$

where B = weight of steam bleed in lb. and 0.46 Btu/lb. °F = unit heat capacitance of steam.

Liquor Side

(*d*) *Temperature Equalisation of Liquor-in.* The quantity of heat given up by F_x lb. of liquor entering at temperature T_{Fx} into effect x is equal to

$$F_x.\sigma_{Fx}\ (T_{Fx} - T_x)$$

where σ_{Fx} is the unit heat capacitance of the liquor. This quantity may be positive or negative according to whether T_{Fx} is above or below T_x.

Where heat capacitance data are lacking, a useful approximation is given by substituting $(2\ W_x + F_x)/3$ for $F_x.\sigma_{Fx}$ in the above expression where W_x is the weight of the water in the F_x lb. of liquor (i.e., taking the specific heat of the solute as 0.3 and considering the heat capacities as additive).

(*e*) *Heats of Concentration.* These can be determined from enthalpy-concentration data, if available. The concentration heat in an effect x is equal to the heat released when E_x lb. of water is added to the correct amount of liquor at the concentration and temperature of the effect, to produce liquor at the incoming concentration, the operation being performed isothermally. If heat is evolved in that dilution, it means that useful heat is being lost in the evaporator, and the concentration heat takes a negative sign. This gives a lead to the experimental determination of concentration heats, bearing in mind that these will change with temperature in accordance with heat-capacitance characteristics.

(*d, e*) *Combined Heats of Temperature Equalisation and Concentration.* When sufficient enthalpy-concentration-temperature data are available, the secondary heats as described in (*d*) and (*e*) preceding can be determined together.

Combined heats = Enthalpy of F_x lb. of incoming liquor at T_{Fx} − (enthalpy of $(F_x - E_x)$ lb. of outgoing liquor + enthalpy of E_x lb. of water, both at T_x).

(*f*) *Superheats.* If there is a boiling-point elevation (bpe) of the order of 10°F or more in the effect, superheat should be taken into account and this is done by considering the evaporation process to operate as follows.

(1) Release of E_x lb. of water at temperature T_x by the reversed dilution process.

(2) Cooling of this water to the boiling point of water at the pressure in the effect, i.e., $(T_x - \text{bpe}_x)$, and evaporation of the water at that temperature where its latent heat is L_x. Sensible heat E_x (bpe_x) in Btu is liberated.

(3) The steam formed is taken back to temperature T_x, absorbing a quantity of heat 0.46 E_x (bpe_x).

In (2) and (3), a net amount of heat is freed for evaporation, approximately equal to 0.5 E_x (bpe_x), the small heat of compression being neglected.

Example on Secondary Heats

To determine the quantity of saturated steam at 50 psig to evaporate 100 lb. of water from a 30% caustic soda liquor fed at 180°F to a single-stage evaporator operating at atmospheric pressure, and concentrating to 50%.

From steam tables, caustic soda concentration-enthalpy chart and Duhring lines, the following data are extracted.

Latent heat of evaporation of water at 50 psig = 911 Btu/lb.

Latent heat of evaporation of water at 1 atm. = 970 Btu/lb.

Enthalpy of 30% NaOH at 180°F ... = 133 Btu/lb.
Enthalpy of 50% NaOH at 290°F ... = 293 Btu/lb.
Enthalpy of water at 290°F ... ... = 258 Btu/lb.
Boiling temperature of 50% NaOH at 1 atm. = 290°F

bpe = 290 − 212 = 78°F

Steam Side. No secondary heats, $h' = 0$.

Liquor Side.

Combined heats of temperature equalisation and concentration, cf. (*d*, *e*).

250 lb. 30% NaOH at 180°F. give 150 lb. 50% NaOH plus 100 lb. of water, all at 290°F.

Enthalpy balance. In: 250 [133] = 33,250 Btu.
Out: 150 (293)+100 (258) = 69,750 Btu.
Heat gain = −36,500 Btu.

Superheat balance (cf. *f*).

Heat released = 0·5×100×78
= 3900 Btu.

$h_x = -36{,}500+3900 = -32{,}600$ Btu.

Equivalent secondary steam input (Equation (1a)).

$S_x = (h'_x + h_x)/L'_x = (0-32{,}600)/911 = -35.6$ lb.

Steam Requirement (Equation (1)). $E_x = (S + S_x)(L'/L)$

$100 = (S - 35.6)(911/970)$

whence $S = 142$ lb.

Computation Procedure

In order to evaluate an evaporator system, some approximation to the operating conditions must first be made. The approximation is conveniently made by dividing the total evaporation and the available temperature drop evenly between the effects. Normally, this crude approximation leads to secondary heat values which may be 20% or more away from the correct values. The r_x and c_x values are of course dependent upon the temperature distribution, but, as stated earlier, for an approximate assay, r_x can be taken as 0.98 throughout the system.

Any large errors in the secondary heats become relatively diminished when compounded with larger correct quantities in the subsequent computation, and the results of an approximate assay based upon average overall data give steam and area values and individual evaporation quantities usually well within 5% of the true values, and quite often within 2%. The individual temperature drops in the effects as found are within 1°-2°F of the true values. The accurate analysis is a repetition of the approximate assay, using the results thereof as data, leading to final values which are as accurate as the basic data could justify. An example of an approximate assay followed by an accurate analysis has been given elsewhere.[1]

In systems where no large boiling-point elevation is involved, the approximate assay usually gives results which are sufficiently accurate for all practical purposes. A criterion of the degree of accuracy is a final evaluation and summation of the individual evaporation quantities as given by Equation (1). Where there is a large boiling-point elevation, the corresponding r_x value in that effect will deviate enough from 0.98 to make an accurate analysis desirable, if not necessary, when the approximate assay follows the simplified procedure using broad approximations.

There are, however, no hard and fast rules as to the application of this method of computation, or the degree of approximation to employ. It is possible, therefore, to work to a procedure, intermediate between approximate assay and accurate analysis, and obtain quite accurate results in a single derivation. This is exemplified in the following example, which is worked according to the standard method in Brown's Unit Operations.[2]

Example

30,000 lb. per hour of 10 NaOH fed at 100°F are to be concentrated to 50% in a triple-effect evaporator in sequence 2:3:1. Steam is supplied at 100 psig (337.9°F) and the condenser pressure is 4 in. Hg. abs. (125.5°F). All effects are of equal area. Calculate the steam input, areas and condenser load. Enthalpy-concentration chart and Duhring lines for NaOH soln. are available. U_1, U_2 and U_3 are taken as 600, 500 and 400 Btu/sq. ft. (°F). respectively.

Approximate Analysis (Hourly Basis)

Feed = 30,000 lb. at 10% = 3,000 lb. soda; 27,000 lb. water

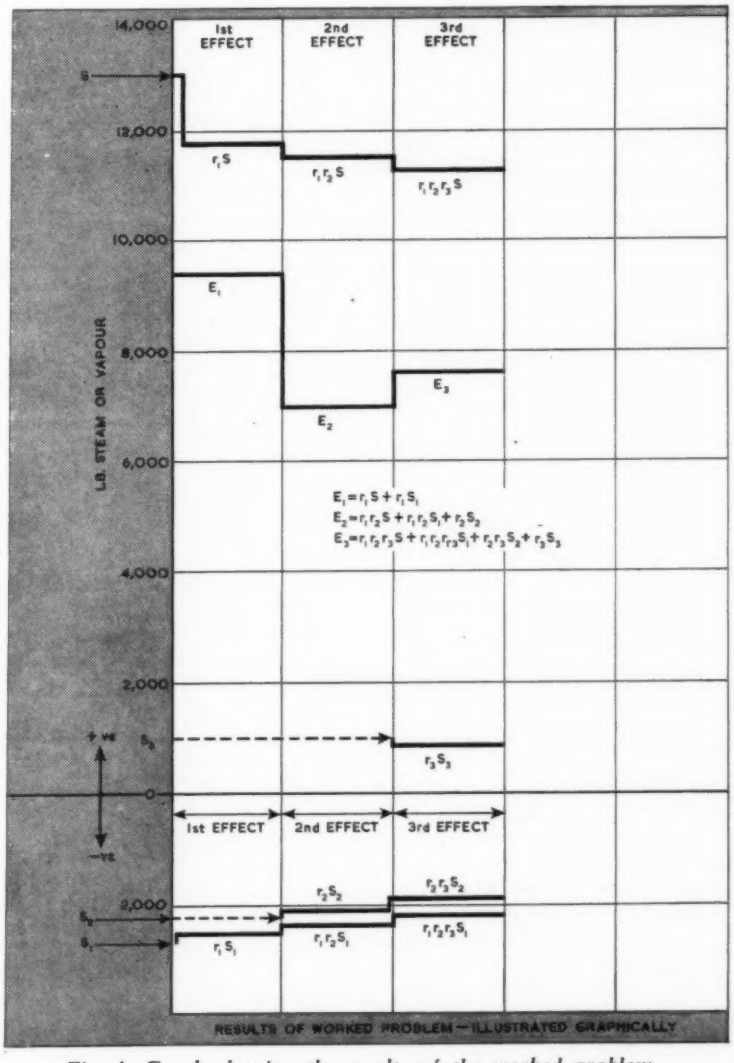


Fig. 4. Graph showing the results of the worked problem.

Product = 50% = 50 : 50 = 3,000 lb. soda; 3,000 lb. water

Total evaporation = 24,000 lb.
Average per effect = 8,000 lb.

A working table is now set out, and relevent information filled in as available or derived.

Effect and flow sequence	Liquor-out amount and composition		Temperature, °F bpe, °F	Steam side	Liquor side	L'_x	L_x	r_x
1 C	3000/6000	= 50%	80	338	302	882	965	0.91
2 A	3000/22,000	= 13.8%	8	222	186	965	991	0.97
3 B	3000/14,000	= 21.5%	16	178	142	991	1022	0.97
			104	126 (Condenser temperature)				

Feed to A, 3000/30,000 at 100°F.

The liquor-out column is first completed in the table, starting from either feed or product, taking due note of flow direction and subtracting or adding E_x = 8000 lb. Agreement with the other end value is a check on the working.

The concentrations are entered and the boiling-point elevations read from the Duhring lines at 300°F, 200°F and 150°F, which inspection indicates will be the order of the temperatures in the effects. (Boiling-point elevations change slowly with temperature. That of 50% NaOH changes by 8°F as the boiling point changes from 200°F-300°F.) The bpe values are entered and summed in the table, and the temperature spread then determined as follows:

Av. $\theta_x = (338 - 126 - 104)/3 = 108/3 = 36°F$.

The complete temperature distribution can then be written in the table. The corresponding latent heats are read from steam tables and entered in the table, and the r_x values calculated and entered. This completes the working table.

The following enthalpy values are then obtained from the NaOH enthalpy concentration diagram:

Temp.
100°F. 10.0% NaOH (60) Btu/lb.
142°F. 21.5% NaOH (93) Btu/lb. Water (110) Btu/lb.
186°F. 13.8% NaOH (137) Btu/lb. Water (154) Btu/lb.
302°F. 50.0% NaOH (302) Btu/lb. Water (270) Btu/lb.

The secondary heat values can now be evaluated, as in the earlier example.

First effect. Using saturated steam. $h'_1 = 0$.

h_1 = (liquor from third effect) (enthalpy) − (liquor-out) (enthalpy) − (water evaporated) (enthalpy) + 0.5 (water evaporated) (bpe)
= 14,000 (93) − 6000 (302) − 8000 (270) + 0.5 (8000) (80)
= −2,352,000 Btu.

Equation (1a). $S_1 = (0 - 2,352,00)/882 = -2670$ lb.

Second effect. h'_2 = superheat in E_1 = 0.46 (8000) (80) = 294,000 Btu.

h_2 = 30,000 (60) − 22,000 (137) − 8000 (154) + 0.5 (8000) (8) = − 2,415,000 Btu.

$S_2 = (294,000 - 2,415,000)/965 = -2210$ lb.

Third effect.

$h'_3 = 0.46$ (8000) (8) = 29,400 Btu.

h_3 = 22,000 (137) − 14,000 (93) − 8000 (110) + 0.5 (8000) (16) = 897,000 Btu.

$S_3 = (29,400 + 897,000)/991 = 935$ lb.

From the r_x values: ($c_1 = r_1 + r_1r_2 + r_1r_2r_2$ and likewise)

$c_1 = 0.91 + 0.88 + 0.85 = 2.64$
$c_2 = 0.97 + 0.94 = 1.91$. $c_3 = 0.97$.

Equation (3). $S = \frac{1}{2.64}(24,000 - 2.64\,(-2670) - 1.91\,(-2210) - 0.97\,(935)) = 13,000$ lb.

Equation (4). $q_1 = 13,000 \times 880 = 11,440,000$ Btu.

$q_2 = q_1 + h_1 + h'_2$
= 11,440,000 − 2,352,000 + 294,000
= 9,382,000 Btu.

q_3 = 9,382,000 − 2,415,000 + 29,400
= 6,996,000 Btu.

Since all areas are equal, Equation (5a) becomes

$$\theta_x = \frac{q_x}{u_x}\left(\theta / \Sigma \frac{q_x}{u_x}\right)$$

$q_1/U_1 = 19,070$ $\theta_1 = (19,070)\,(108/55,330) = 37.2°F$
$q_2/U_2 = 18,760$ $\theta_2 = (18,760)\,(108/55,330) = 36.6°F$
$q_3/U_3 = 17,500$ $\theta_3 = (17,520)\,(108/55,330) = 34.2°F$

$\Sigma q_x/U_x = 55,330$ (≡ 108°F) 108°F

Equation (5). $A = (q_1/U_1)/\theta_1 = 19,070/37.2 = 513$ sq. ft.

Equation (1). $E_x = r_x\,(E_{x-1} + S_x)$

		Smoothed values
$E_1 = 0.91$	(13,000−2,670) = 9,400 lb.	9,390 lb.
$E_2 = 0.97$	(9,400−2,210) = 6,970 lb.	6,960 lb.
$E_3 = 0.97$	(6,970+ 935) = 7,660 lb.	7,650 lb.
	24,030 lb.	24,000 lb.

Condenser load, assuming final condensate out at 100°F,
= 7,650 (1022+[142−100]) = 8,150,000 Btu
(i.e., latent heat content of E_3+available heat when condensed).

Comparative Table of Results

		Approximate analysis	Standard method as worked by Brown
Steam consumption		13,000 lb.	13,076 lb.*
Area		513 sq. ft	505 sq. ft
			503 sq. ft
			499 sq. ft
Evaporations.	E_1	9,390 lb.	9,281 lb.
	E_2	6,960 lb.	6,999 lb.
	E_3	7,650 lb.	7,720 lb.
Temp. drops.	θ_1	37.2°F	35.9°F
	θ_2	36.6°F	38.0°F
	θ_3	34.2°F	36.0°F
Condenser load.		8,150,000 Btu.	8,075,120 Btu.

** Editions 1 and 2 of the textbook give 12,076lb. This is an evident misprint as confirmed by Prof. Brown (private communication). A figure of 467 sq. ft in the text corrects to 505 when the steam value is corrected.*

In a problem of this nature, the weak point in the data is the approximative or often tentative value that can be given to a heat-transfer coefficient, and the certainty that the heat-transfer coefficients will anyway change to some degree with changes in operating conditions and as the heating surfaces become fouled.

Assessment of Modifications

Equation (3b) is useful in giving an indication of the likely effect of modifications to an existing evaporator system. To illustrate its use, potential modifications to the system just analysed will be considered.

It is required to estimate the steam saving that would be achieved:

(*a*) by preheating the feed using vapours from the last effect and all condensates in separate heat exchangers;

(*b*) by preheating the feed with first condensate and flashing second condensate forward; and

(*c*) by flashing all condensates forward.

(*a*) In this case, the net additional heat recoverable from the final vapour is hardly sufficient to justify its use, but it saves some cooling water as well. The feed could possibly pick up 10°F here.

The condensates available are: 13,000 lb. at 338°F, 9400 lb. at 222°F, 7000 lb. at 178°F.

The 30,000 lb. of feed delivered at 110°F can pick up

about 15°F from the third condensate. The feed now at 125°F can pick up a further 26°F from the second condensate. The feed now at 151°F can pick up a further 75°F from the first condensate, rising to 226°F. The changes to be considered are, then, the additional heat given to the second effect and the consequent change in S.

$\triangle S_2$ = additional heat in feed = 30,000 (226−100) Btu
= 3,800,000 Btu = 3800 lb. steam equivalent.

Equation (3b) $\triangle S = 1/C_1\ (\triangle E - c_1\triangle S_1 - c_2\triangle S_2 - c_3\triangle S_3)$
$= 1/2.64\ (0-0-1.9\ [3800]-0)$
$= -2700$ lb. Steam saving = 2700 lb.

(*b*) At 100°F the feed could pick up about 95°F from the first condensate.

$\triangle S_2 = 30{,}000\ (95)/1000 = 2850$ lb.

Extra heat available from condensate flash to third effect. $\triangle S_3 = 9400\ (222-178)/1000 = 410$ lb.

$\triangle S = 1/2.64\ (0-0-1.9\ [2850]-0.97\ [410])$
$= -2200$ lb. Steam saving, 2200 lb.

(*c*) The first condensate flashing from 338°F to 222°F gives to the second effect:

$\triangle S_2 = 13{,}000\ (338-222)/1000 = 1500$ lb.

The combined condensates (13,000+9400 lb.) leaving the second effect at 222°F give to the third effect:

$\triangle S_3 = 22{,}400\ (222-178)/1000 = 1080$ lb.

Whence, $\triangle S = 1/2.64\ (0-0-1.9\ [1500]-0.97\ [1080])$
$= -1500$ lb., i.e., steam saving = 1500 lb.

The incremental method can only be very approximate in so far as any change in conditions will upset the temperature balance as well as the heat-transfer coefficients. The result is likely to be more accurate than that obtained as a difference between two calculated total steam consumptions. This method therefore appears to be a useful tool in the design of multiple-effect evaporator systems.

---

[1] *Industrial Chemist*, 1957, July, p. 331.
[2] Brown, G. G., *et al.* "Unit Operations", first edition, Chapman & Hall, London, 1950 pp. 489-91.

SOME EVAPORATOR MANUFACTURERS AND THEIR PRODUCTS

MANUFACTURER	TYPES MADE	DUTIES FOR WHICH EQUIPMENT IS SPECIALLY DESIGNED	SPECIAL MATERIALS OF CONSTRUCTION	MAXIMUM EVAPORATIVE CAPACITY PER STAGE
Apex Construction Ltd., 15 Soho Square, London, W.1.	External calandria.	Low-temperature evaporation of pharmaceutical and similar substances. Foaming liquids.	Stainless steel.	10 to 150 gal./hr.
Blairs Ltd., Woodville Street, Glasgow, S.W.1.	Patent three- or four-stage climbing-film evaporators, pressure or vacuum; falling-film pressure-evaporators; immersed calandria forced-circulation flash evaporators; bulk-type continuous evaporators; and single-stage batch finisher evaporators.	All trade liquors, including gelatine, malt, glucose, acid metallic oxides, tanning extracts, meat extracts, fertiliser salts and distillery effluents.	Copper, phosphor-bronze, stainless steel, rubber or neoprene lined.	To specification. (Largest so far designed, 25,000 lb./hr.)
S. Briggs & Co. Ltd., Burton Engineering Works, Burton-on-Trent.	Internal and external calandria.	As specified.	Stainless steel, copper, Monel and other metals.	To specification.
British Acheson Electrodes Ltd., Grange Mill Lane, Wincobank, Sheffield.	Shell and Tube; climbing film.	Corrosive liquors.	Karbate impervious graphite.	Based on 2010 sq. ft.
Kestner Evaporator & Engineering Co. Ltd., 5 Grosvenor Gardens, London, S.W.1.	Climbing and falling film; multi-circulation; horizontal film; and forced-circulation—salting type. Available as single or multiple effect, and with thermo-compression.	All industrial liquors—organic and inorganic, acid and alkaline. Heat-sensitive products, such as biological extracts. Food products, such as milk and fruit juices.	All standard materials, including stainless steel, nickel, Monel, high-silicon iron, etc. Also non-metallic contact using Keebush and carbon.	To specification.
Nordac Ltd., Uxbridge, Middlesex.	Submerged combustion.	Most aqueous solutions, especially those with scaling or corrosive properties.	Rubber, acid-proof brick, carbon, etc. Linings where necessary.	11,000 lb./hr.
Powell Duffryn Carbon Products Ltd., Springfield Road, Hayes, Middlesex.	Single and multiple effect—vacuum, atmospheric and above atmospheric pressure; natural or forced circulation.	Rare earth chlorides, protein liquors, spin-bath acid; ammonia solutions, sulphuric and hydrochloric acids.	Carbon and graphite.	100 to 20,000 lb./hr.
Power-Gas Corporation Ltd., Stockton-on-Tees.	Any type, to design and specification. Krystal concentrating and crystallising evaporator.	Solutions containing impurities which normally foul heating surfaces. Crystallisation of salts in uniform size and shape.	Rubber-lined mild steel, stainless and clad steel, Monel, nickel, aluminium, copper, and thermo-setting plastics.	About 45,000 lb./hr. of water.
Geo. Scott Ltd., Artillery House, London, S.W.1.	Natural and forced circulation, external calandria. Film and salting types; multiple-effect and vapour recompression.	All trade liquors. Caustic soda and alkalis; organic salts and acids; fruit juices; milk products; black liquors; brine; protein liquors.	Stainless-steel clad steels, copper, nickel, Monel, etc.	100 to 35,000 lb./hr and upwards
Duncan Stewart & Co. Ltd., Summer Street, Glasgow, S.E.	Triple, quadruple and quintuple evaporators with tubular calandrias.	Evaporating sugar juices.	Stainless and stainless clad steel.	

INSTRUMENTATION FOR MULTI-EFFECT EVAPORATORS

by M. H. GRIMES, B.Sc.

This article indicates ways in which instrumentation can be applied to integrate the operation of individual evaporator effects with that of others, and with the demands of the factory

ONE of the larger steam-consuming unit processes in many chemical factories is that of evaporation and, where feasible, this is carried out in cascaded units to obtain greater steam economy than is possible with one unit. Although perhaps consisting of five or six separate evaporator effects, these will be operationally interdependent, and to work together smoothly as one unit will have carefully engineered and efficient controls. Since evaporation is usually a key process in a chemical factory, the control instruments must be reliable, and be such that they can be quickly and easily maintained and serviced. Moreover, since break-downs can occur occasionally, all controls should fail to safety wherever possible. Reliable records of power consumption, required for costing and planning purposes, are an additional reason for the use of instrumentation. Control and measurement systems finally adopted with any given evaporator installation will take account not only of the type of unit and the industry served, but also the part played by the evaporator in the process and the available skill of operational and maintenance personnel.

For fast controller response and accurate regulation the number of process lags between the point of measurement (flow meter) and the point of control (flow control valve) must be kept to a minimum to reduce the time constant of each of these lags. An evaporator installation working under backward feed will give better control of density than the same installation working with forward feed; furthermore, controllability improves as the number of effects decrease.

During operation the thick-liquor output rate will vary, and in certain circumstances will tend to cease altogether. In such cases, the output density-measuring instrument should not be located directly in the liquid draw-off line without making provision for recirculation of the liquor back to the first effect. This is because the response of the density controller will be based upon the signal from the density-measuring instrument—which must be representative of the liquid in the last effect.

Submerged Tube Evaporators

Product Quality. This is usually controlled against the density of the thick liquor leaving the system, although in some cases, e.g., tomato juice, control should be based upon liquid consistency. It is sometimes possible to control the density against the boiling temperature in the last effect, but for this to be reliable it is necessary also to stabilise the pressure in the vapour space of the last effect. If, as is quite likely, air is present in this vapour, it will upset the relationship between liquid concentration, boiling temperature and total pressure above the boiling liquid. Consequently, the controlled output density will go down although the boiling temperature will remain steady.

Measurement Method. Liquid density may be measured directly by a special transmitter which compares the upthrust on a submerged float with an air signal. This has the advantage of being consistently accurate and vacuum tight, but cannot be used with viscous liquids, or in any application where solids or crystals may be precipitated from the concentrated liquid.

Another method of determination measures the change in hydrostatic head between two fixed points in the liquid (separated vertically) with change in liquid density (see Fig. 1). Satisfactory dynamic operation under conditions of changing density is defined by the following expression:

$$p\frac{dv}{dt} > h\,V\frac{ds}{dt}$$

where $\frac{dv}{dt}$ = air purge rate, cfh, measured at p, psia;

V = total volume, cu. ft, of lower bell, dip-tube, transmitter measuring chamber, etc.;

h = depth, in., of lower bell below surface; and

$\frac{ds}{dt}$ = maximum rate of increase of density, lb./cu. in./hr.

The liquid level in the measuring vessel should be stabilised as shown, by providing it with an overflow into a second vessel, which should be equipped with a simple level control if necessary. If the level alters, it should not do so at a rate greater than that given by:

$$p\frac{dv}{dt} \geqslant Vs\frac{dh}{dt}$$

where s = liquid density, lb./cu. in.; and

$\frac{dh}{dt}$ = rate of increase of liquid level, in./hr.

As can be seen from the above, the air volume enclosed by the air-purge system should be small, but the bells at the bottom of the dip-tubes should not be omitted alto-

Mr. Grimes was educated at the John Fisher School and Battersea Polytechnic, London. He graduated in 1953, was employed by The Gas Council from 1953 until 1955, and is now a systems engineer with Electroflo Meters Co. Ltd.

gether, because they reduce the influence of liquid level changes and the surface tension. The rate of supply of water to the range suppression chamber need only be large enough to make good losses by evaporation, i.e., a few ounces a day.

The density of the output liquor will depend upon the ratio of liquor-feed rate to steam-supply rate, and upon inlet liquid density, which is the independent variable. We can therefore control output density by regulating this ratio, usually by stabilising one variable (steam rate for submerged-tube units) and regulating the other to maintain constant output quality.

Level Controls. These should be fast in operation to reduce the time constant of the density control loop. Liquid throughputs will normally be controlled by a valve in the output line, so liquid levels in the system will be controlled by regulating the inlet to each effect. These controllers should have proportional actions. The liquid level is normally measured by means of a differential pressure transmitter which can be steam purged if required. Alternatively, the upper pressure tapping can be provided with a condensation chamber, as shown in Fig. 2. Another method of level measurement determines the upthrust on a cylindrical float suspended vertically, and partly submerged in the liquid. In the case of a climbing-film evaporator, it is only necessary to prevent flooding in the separator. In the case of a submerged-tube evaporator, however, the heat-transfer coefficient depends largely upon the liquid level, and this should be maintained at a value somewhere between 10% and 90% of the tube height. The optimum level will depend upon the liquid being treated and the heat-exchanger design.

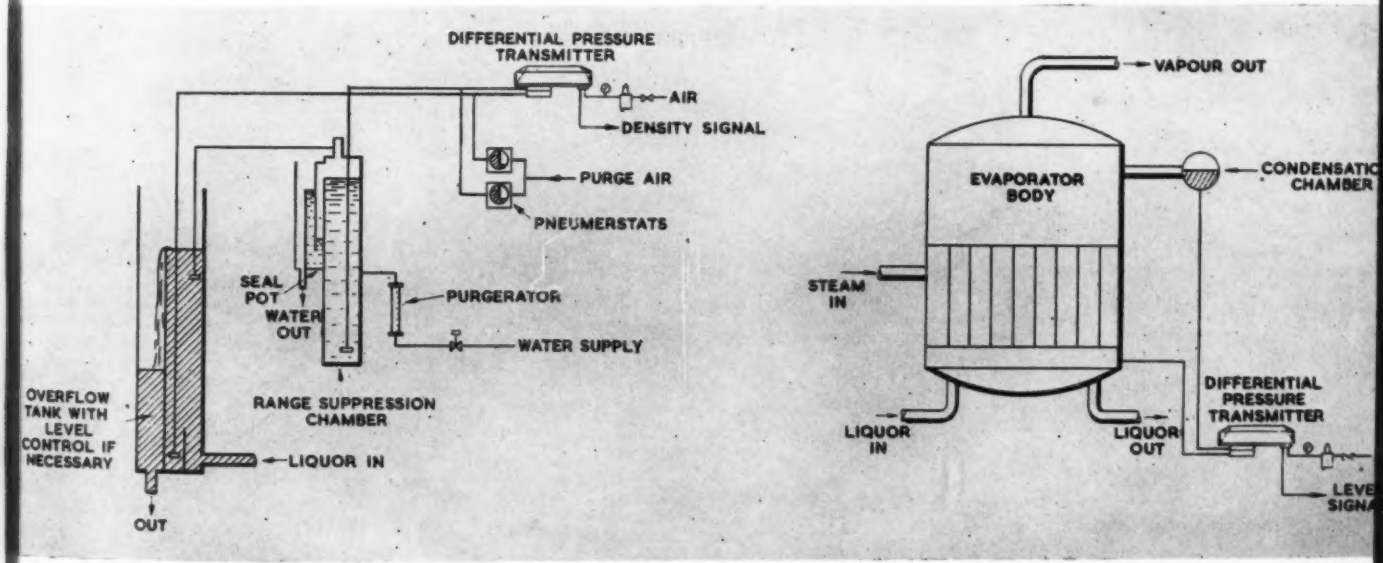
Condensing Pressure. It is usual to control the pressure in the vapour space of the last effect by regulating the supply of water to the condenser; the vacuum backing-pump working independently at constant speed. Provided the backing pump is of adequate capacity, this method works well and stabilises the temperature of water leaving the condenser at about 50°C. This is used to augment factory hot-water services (see Fig. 3). In conjunction with the density controller, the pressure controller stabilises the boiling temperature in the last effect. This latter point is of some importance where crystallisation from the thick liquor is liable to occur, for this tendency will increase with a decrease in liquid temperature.

A surface heat exchanger is sometimes provided in addition to a direct-contact type to carry part of the condensation load. In this case, a controller will be required, regulating the cooling water flow to maintain a constant temperature differential between the incoming vapour—from the last effect—and the outgoing cooling water.

Steam Supply. The system so far described, with density, condensing pressure and level control, is complete, and will operate steadily at a rate determined by the heat-input rate. If maximum output is required continuously, then the steam input can conveniently be controlled against the pressure in the first effect. This will compensate for varying input steam pressures and for scaling on the first effect (particularly useful with backward feed installations), and will maintain the pressure in the vapour space of the first effect at its designed maximum—usually the factor limiting the rate of working. However, the rate of evaporation is normally required to keep step with either availability of liquid supply or with the capacity of following processes or product storage. The steam supply is therefore controlled against an air signal representing thin-liquor level in the feed tank, or product storage capacity (tank level), or product-treating capacity, or a combination of these factors (see Fig. 4). The steam controller should have a proportional band width such that it operates the evaporator at its minimum rate as, for example, when the feed tank is nearly empty. The supply tank should have a time constant large with respect to that of the system.

It is undesirable to allow the evaporator to be shut-down completely due to non-availability of thin liquor, so an additional control comes into operation when the feed tank is nearly empty, i.e., when the evaporator is operating at its minimum handling capacity. This is an on/off control which switches on a supply of water to the evaporator inlet. The evaporator system, being self-correcting, gradually shuts-down the density control valve keeping the output density constant, so that the plant "marks time". Restoration of the feed shuts off the water supply and the unit gradually returns to normal. This control is particularly important when (as occurs in the sugar industry) steam from the first and perhaps subsequent effects is used to supply process steam to vacuum pans and other equipment. If the steam supply pressure is likely to vary con-

Fig. 1 (left). Measuring the change in hydrostatic head between two fixed points is one method used for density determinations. Fig. 2 (right). Method of measuring liquid level in an evaporator body.



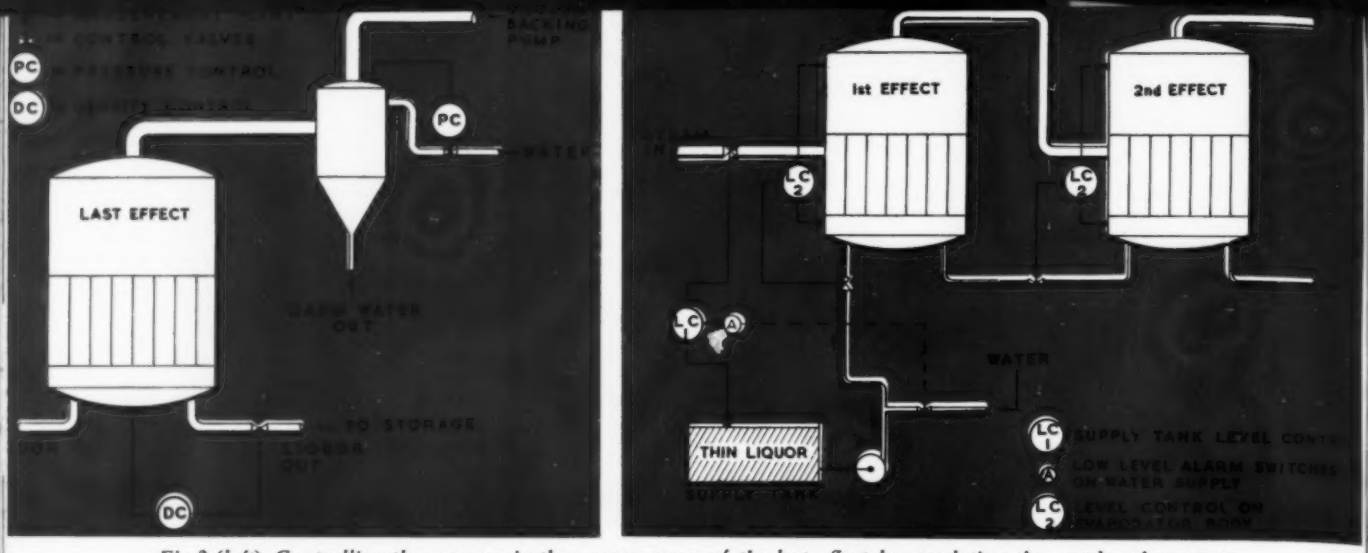


Fig 3 (left). Controlling the pressure in the vapour space of the last effect by regulating the supply of water to the condenser. Fig. 4 (right). How control of steam supplies may be effected.

siderably during operation, the steam supply should be controlled against the vapour pressure in the first effect, and the control point for this pressure should be set by the liquid level in the supply tank as before, i.e., as a cascade control system.

Desuperheater Control. The film-heat-transfer coefficient between steam and a dry surface is considerably lower than that between steam and a wet surface, so the steam applied to the first effect should be close to saturation. If, as is quite probable, the supply steam is superheated, then a desuperheater will be required. This will have automatic controls as shown in Fig. 5. Admission of fresh steam is regulated to provide a constant outlet pressure, and the desuperheating water spray is controlled to maintain the temperature of the steam leaving the desuperheater at a value slightly above saturation at this pressure. These controllers can interact if incorrectly set, and as their response is asymmetric, they will require careful adjustment. The temperature control point should not be less than 10-15°F above the calculated saturation value, and to ensure complete evaporation of the injected water the length of straight pipe below the water spray should not be less than 30 pipe diameters (or 30 ft, whichever is the greater). The temperature-sensing element must be located at a point where the injected water has completely evaporated and where the steam is thoroughly mixed at all expected flow rates. In addition, a high-temperature alarm should be provided to operate in the event of cooling water failure.

Stepwise Control of Steam Ejectors

Vapour Recompression Control. Advantage may be gained by recompressing the vapour generated in the first effect and using it to augment the steam supply to the first-effect calandria. If this is achieved with high-pressure steam ejectors, they can be controlled (stepwise) to keep the pressure in the steam-supply main constant. If three ejectors are used (see Fig. 6), their capacities should be in the ratio 1:2:3. By employing combinations of these ejectors, the rate of pumping can be adjusted between 0 and 6-in. unit steps—ejectors are designed to work efficiently at only one rate, so throttling control on the live-steam supply is not satisfactory.

Selection of the ejectors is accomplished by means of cam-controlled micro-switches and pressure-operated solenoid valves. The cams are positioned by a servo regulator in conjunction with a controller. If both desuperheater control and recompression control are employed together, then attention must be given to their action and adjustment as interaction will occur if they overlap.

Pumps and Valves. In an evaporator layout employing backward feed, liquid has to be pumped from one effect to the next against a pressure head. This flow of liquid can be controlled either by allowing the pumps to work at constant speed and allowing a regulated quantity of liquor to by-pass the pumps via a control valve, or by employing a variable-speed gear controlled by a diaphragm motor loaded by the controller output. If self-priming centrifugal pumps are used, then it is possible to employ a control valve directly on the pump outlet.

In the case of forward-feed evaporators, flashing may occur at the seats of the control valves employed for letting down the liquid from one effect to the next, since the downstream pressure will be below the saturation vapour pressure at the liquid temperature. This phenomenon will reduce the effective port area, but special types of control valve are available for dealing with this problem and the correct type to be employed should be ascertained from the valve makers. Valves with linear transfer characteristics should be used for level and steam controls, but equal percentage valves can be employed with advantage for the density-control valve. Also, since the interior of the installation will operate at pressures below atmospheric, efficient valve-spindle seals should be employed to minimise air leaks which would otherwise interfere with the operation of the unit.

During plant start-up, the total space in the evaporator system will be evacuated to the condensing pressure (usually about 26 in. mercury vacuum), so all control valves and pressure-measuring instruments should be capable of withstanding this vacuum without damage. The steam-supply control valve will be subjected to a large pressure differential when in the closed position if steam is applied to its upsteam side during start-up. This valve, which may be a large butterfly type, must be robust enough to withstand the forces set up by such pressure conditions.

Direct Feedback. Density control of the liquor feed to the installation is sometimes employed, and this is achieved by mixing a regulated quantity of thick liquor with the thin liquor and feeding the resultant mixed liquor to the unit. This control is fast-acting and close stabilisation of the feed is possible, giving, in conjunction with the main density regulator, accurate control on the output density for wide and sudden changes of thin-liquor quality. The feed-density-control point should be set just above the highest thin-liquor density likely to be handled.

Single-pass long-tube Evaporator. In this type of evaporator there is no liquid level in the evaporator body, the liquid being fed once through at a controlled rate. After leaving the tube-bundle, the liquid, travelling at high

velocity, strikes a baffle and passes to a separator. The liquid level in the separator is frequently controlled by regulating its outflow. In such circumstances the density control valve will have to be placed on the liquor-inlet line. Indifferent density control will be obtained by this method, since the density-measuring point will be on the last effect, whilst its control valve will be on the inlet—with the lags associated with the intermediate effects included in the control loop. Fortunately, long-tube units are frequently employed under backward-feed conditions, so it is possible to obtain good density control by regulating the steam-inlet flow whilst the liquor-flow rate is controlled independently, e.g., against liquor level in the supply and/or intermediate tanks.

After a few weeks (or months) in service, the inside surface of the calandria tubes will become encrusted with scale which reduces the heat-transfer coefficient of the heat exchangers. As the plant will usually be working with limited inlet steam pressure, this will also reduce its maximum handling capacity. The density controller can be designed to prevent the plant "running-out of steam pressure"—required to maintain the correct ratio between net-heat input rate and liquor rate. In such a case an alarm, arranged to operate in the event of consistently low density, can automatically reduce the liquor rate (see Fig. 8), thus bringing the density controller back into command of the situation.

General Considerations

It occasionally occurs that a liquor tank is interposed between two of the evaporator effects—for the purpose of skimming, filtering or clarifying. In this case, the liquor supply to the preceding effects can be controlled against the level in this tank, whilst the steam supply is controlled against the supply tank level, as described above. If the supply liquor is fed to two effects in parallel, then a flow ratio control must be provided to ensure correct distribution of the load between these two effects. This can be provided automatically by controlling one flow against the other in a ratio automatically fixed by a ratio relay. Since the flow-ratio control valve will be placed on the inlet side of these effects, it follows that the liquid-level control valves must be placed on the outflow lines, and the remarks made under the heading "Long Tube Evaporator" will apply.

If the steam from the vapour space of the first, and perhaps subsequent effects, is used for extraneous process heating, then additional controls will be required to maintain these pressures constant. A satisfactory method is shown in Fig. 7. It will be noted that the main-heat-input control valve has been moved from the inlet side to the vapour line between the second and third effects. In this position it will influence the steam supply to the subsequent effects and also the steam load on the first two effects, although its action will be decoupled by the abstraction of vapours for external process use.

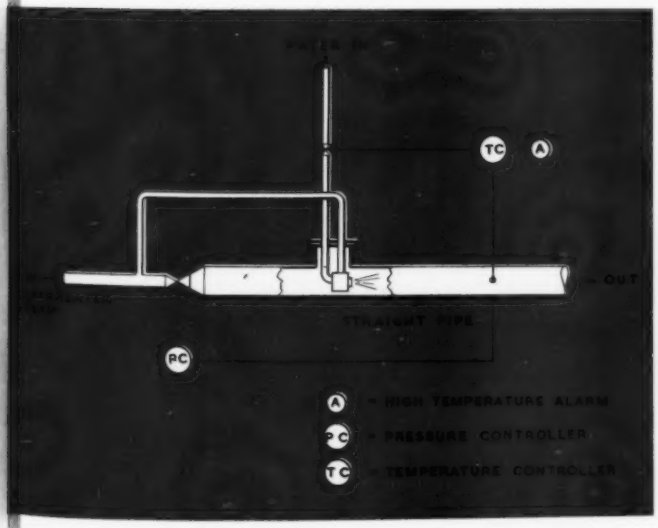
As shown, instruments will also stabilise the steam pressure supplied to the external processes. When this system is employed, greater percentages of water are extracted by the first two effects than by subsequent effects, i.e., greater concentration occurs in either of the first two effects than in any of the subsequent effects. The density controller is working from the output end, so this asymmetric distribution of concentration load will also gradually decouple the density controller and make accurate control of density more difficult. Due to the relationship between initial concentration and change in concentration per lb. of water extracted, this will not have serious results unless relatively large amounts of steam are extracted from the vapours leaving the first few effects.

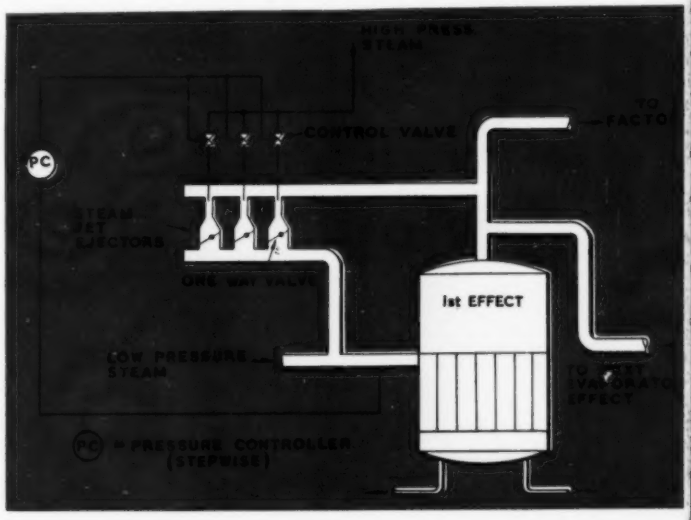
It will not be possible to control density by regulating steam rate if vapours are extracted from any of the evaporator effects for factory-heating purposes. Under these circumstances, with a constant liquor rate, the final liquor density will depend upon the ancillary steam load which is unlikely to remain constant.

Liquid condensate from the first and sometimes the second effects is usually returned to the boilers for re-use. A conductivity cell placed in this line will detect contamination of the liquor due to a leaky evaporator or, for second-effect condensate, to liquid entrainment. This instrument should automatically switch the returned condensate from the boiler line to drain, thus safeguarding the boiler installation.

It is possible to increase the handling capacity of the system, during periods of peak demand, by reducing the controlled output density, by increasing the vacuum in the last effect, or by a combination of both. The extent by which the capacity can be increased by reducing the condensation pressure alone is limited, as beyond a certain point the consequently reduced temperature and increased viscosity lower the heat-transfer coefficient in the last effect,

Fig. 5 (left). Diagram illustrating the automatic control of the superheated steam supply. Fig. 6 (right). Recompressing the generated vapour in the first effect allows for stepwise control of the steam ejectors.





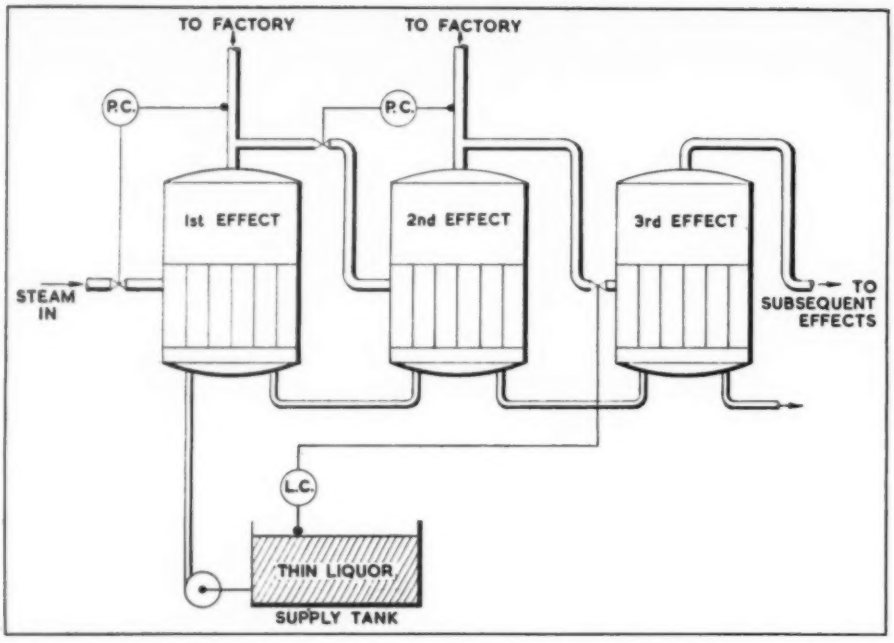


Fig. 7. Diagram illustrating how additional controls, required when steam from the first and other effects is used for extraneous process heating, are positioned.

with the net result of reduced capacity and lower condenser water temperature. This may be inconvenient if this water is used to supply other processes, e.g., sugar-beet digesters. This action can be achieved automatically, but it should be remembered that precipitation of crystals from the liquor will occur if the liquid temperature falls low enough to give a super-saturated solution in the last effect. Other instruments required include temperature indicators and/or recorders connected to resistance bulbs located in the boiling liquid, condenser water outlet, condenser water inlet, thin-liquor inlet and at any intermediate tanks and heaters as required.

Inlet liquor density, liquid level in the supply tank and in the output storage tank, steam consumption and steam supply pressure, thin-liquor flow rate, and on some installations thin-liquor density, are other variables which are well worth recording. Pressure indicators also should be provided to measure steam supply pressure, condensation pressure and the pressures in the steam spaces of each effect. Finally, the centralised instrument panel should have on/off controls and indicator lights for all the key process pumps.

The author wishes to thank the directors of Electroflo Meters Co. Ltd. for permission to publish this article and for their assistance in its preparation.

READING LIST

Broida, V. *Genie Chim.* (supplement to *Chim et Ind.*), **73,** 1955, 153-62; **74,** 19-26.
Young, W. S. *Sugar*, **48,** 1953, (3), 48-50.
Camp, A. C., and Slater, L. E. *Chem. Eng.* **57,** (9), 108-11.
Ziegler, J. G. *Taylor Technology*, **2,** 1949, (3), 18-22.
Solodkovskii, A. M. *Sakhar. Prom.*, 1955, (7), 23-8.
"Pulp & Paper Manufacture", Vol. 1 564-8, McGraw-Hill, London, 1952.

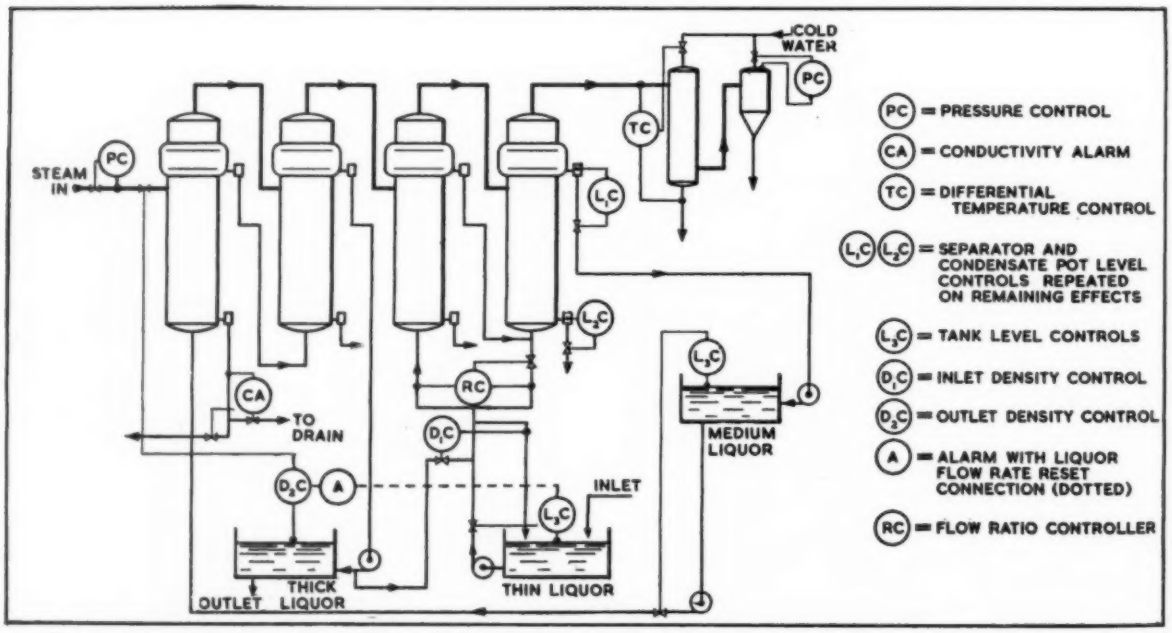


Fig. 8. To prevent the plant running-out of steam pressure, an alarm can be arranged to reduce the liquor rate so as to cause the density controller to take correcting action.

SURFACE HEATED TANKERS

A new application of electrical heating which, it is claimed, should enable an extended range of chemical products to be transported in liquid form by road

THE surface heating of road tankers has now been made possible with the use of equipment available from Isopad. The new system makes good the loss of heat from insulated tankers and acts, the makers say, as an insurance against solidification or deterioration of the contents of a tanker. Substances already being successfully transported in tankers heated in this way include sulphur, chocolate and phthalic anhydride. The suitability of the method is being explored for, among other substances, bitumen, lubricating and heavy fuel oil, coal-tar fuels, stabilised sulphur trioxide and acetic acid and this list is expected soon to be extended considerably.

The equipment consists of electrical heating panels, to which the name Iso-panel has been given, which are heat-insulated on the outside and, during the journey, are energised by a generator mounted between the driving cab and the tank. The generator provides electricity at mains voltage, so that at the loading and delivery stations mains electricity may be employed if convenient. The surface heated road tankers are made in the capacity range of from 5 to 15 tons.

To keep the electrical loading (see Fig. 1) on the panels to a minimum, good heat insulation is aimed at, and a 95% efficiency is usually achieved. The heat loadings can vary from 10 to 200 watts per square foot of panel according to the application and the surface area to be heated. For materials that are heat-sensitive or difficult to melt, the whole of the surface of the tank normally is lined with the heating element, but for substances that will withstand sufficient heating to cause convection currents, only part of the surface need be warmed.

A number of safety devices are incorporated in the equipment, among them being the division of the heating unit into 12 or more independent circuits so that if one is damaged the tank can still be maintained at the correct temperature. In an emergency, for example, to melt solidified substances, the panels can be connected in parallel to provide, without overloading, four times their normal power. For the carriage of inflammable materials flameproof heating panels are employed and a firescreen is placed behind the generator, which itself is not flameproof.

Usually the temperature recorded is that of the liquid contents, but, with poor heat-conductors or heat-sensitive materials, surface temperature can be indicated and used as the controlling value. A shunt control on the alternator providing for a voltage variation of 150-250 volts is normally used to alter the temperature. Although the adjustment can be carried out automatically, usually this is made the responsibility of the driver. In practice, there is little danger of overheating the contents, for at maximum power the temperature rise is only ½-2°F an hour, and at the lowest energy output of the generator the temperature drop would not be more than ½°F per hour.

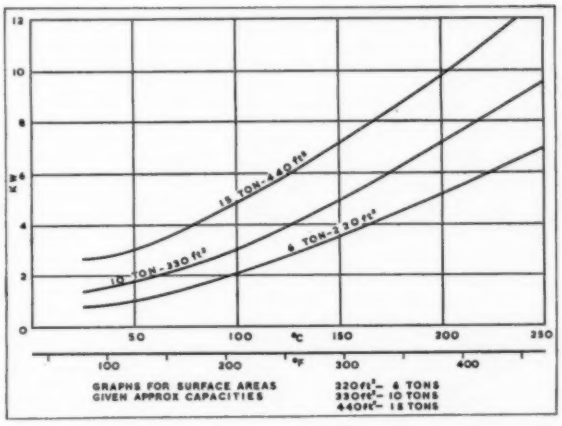


Fig. 1. Minimum electrical loadings, assuming each tanker is lagged with a glass-wool layer 3-3½ in. thick

The heating element and insulation is available in two forms: (a) as lagging boxes, which are self-contained, detachable sections composed of heating panels with a backing of lagging (glass wool or equivalent insulation); and (b) heating panels for applying to the tanks directly and for subsequent backing by a 3- to 4-in. layer of insulating material. It has been found that with the thickness of lagging normally used the contents of a tanker drop by 1-6°F per hour according to the temperature of the material carried and the weather conditions. The outer skin fitted to the tank is made in sections for ease of access to the panels.

Information which the user should supply to enable the equipment to be designed for a particular tanker includes the temperature of filling of the material to be carried; the minimum temperature for delivery (which could be the temperature of filling); the viscosity (if low, so that convection currents are easily established, it may only be necessary to heat part of the tank); specific heat (for use in case of possible reheating); mains voltage; and whether the tanker should be "flameproofed".

SUBMERGED COMBUSTION EVAPORATORS

Industrial applications for the submerged combustion evaporator are described, including that of difficult effluents such as those issuing from coking, titanium oxide and pickling plants

by J. AUSTIN, B.Sc., A.M.I.Chem.E.

IF gaseous or oil fuel is burned in a chamber partly submerged in a liquid so that the resultant hot products of combustion are released below the liquid surface, then the process is termed Submerged Combustion. The combustion products bubble to the liquid surface, transferring heat to the liquid. If sufficient heat is applied in this way the liquid boils, so giving rise to Submerged Combustion Evaporation.

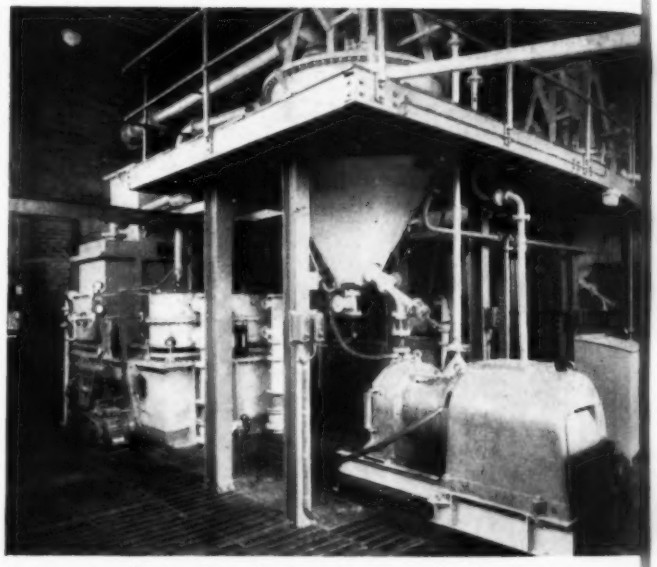
A submerged combustion evaporator in its simplest form is shown in Fig. 1. The evaporator vessel, which is essentially only a holding tank, is fitted at one end with a duct for the outlet of the evaporated steam and residual gases from the burner. At the other end, mounted in the cover, is the gas burner, the cylindrical combustion chamber being about half submerged. The lower end of the chamber is open, but the flow of gases prevents entry of the liquid. Gas and air are supplied, suitably pressurised, to a mixing head and thence to the chamber, where complete combustion occurs. The hot combustion gases bubble from the chamber, creating violent agitation of the liquid and, by the time these gases reach the surface, heat transfer is complete, the exit temperature being within 1°C of the liquid temperature.

Comparison with other Direct Evaporators

Submerged combustion is only one of several techniques of evaporation using direct contact between liquor and hot gases. The Porion evaporator was developed for the beet-sugar and paper industry and consists of rotating vanes which dip into the liquor and are then exposed to the hot gas. The Gaillard tower of the sulphuric acid industry is a tower up which flow hot gases countercurrent to the acid.[1] Spray evaporators and spray driers also depend on the direct contact of liquid with hot gases.

The Kessler sulphuric acid evaporator[1] more nearly approaches submerged combustion, the hot gases from a furnace being directed under a series of walls which dip just below the acid surface. The "Drum"[1] acid concentrator can be regarded as a development of this idea. If one compares the processes mentioned, one feature of submerged combustion becomes clear—namely, that the heat is released as close as possible to the point where it is used. External cooling of the combustion chamber is effected by the boiling liquor in the evaporator. This close proximity of heat release and heat utilisation helps to reduce heat losses.

Mr. Austin is a graduate of King's College, London, and was for some years with the U.K. Atomic Energy Authority. He is now Senior Chemical Engineer with Nordac Ltd., Uxbridge.



A two-unit submerged combustion plant used for the concentration of spent pickle acid. (Photo: Steel Company of Wales.)

Boiling Point and Heat Efficiency

All evaporators involving direct contact of gases with the liquor are subject to the partial pressure law. Steam from a submerged combustion evaporator leaves mixed with a quantity of inert gases consisting of CO_2, N_2, excess air and possibly a little SO_2. The liquor boiling point thus depends on the partial pressure of steam in the mixture. In practice, this partial pressure effect is useful in reducing the boiling point 10° to 20°C below the value at atmospheric pressure. For instance, it offsets considerably the steep rise of boiling point when concentrating sulphuric acid and thus eases the materials of construction problem.

Apart from a small quantity of heat in the pressurised air supply to the burner, the heat input of a submerged burner is the gross calorific value of the gas or oil used. In a single-effect evaporator the water formed by combustion of the hydrogen in the fuel is not condensed and the difference between gross and net calorific values is lost to

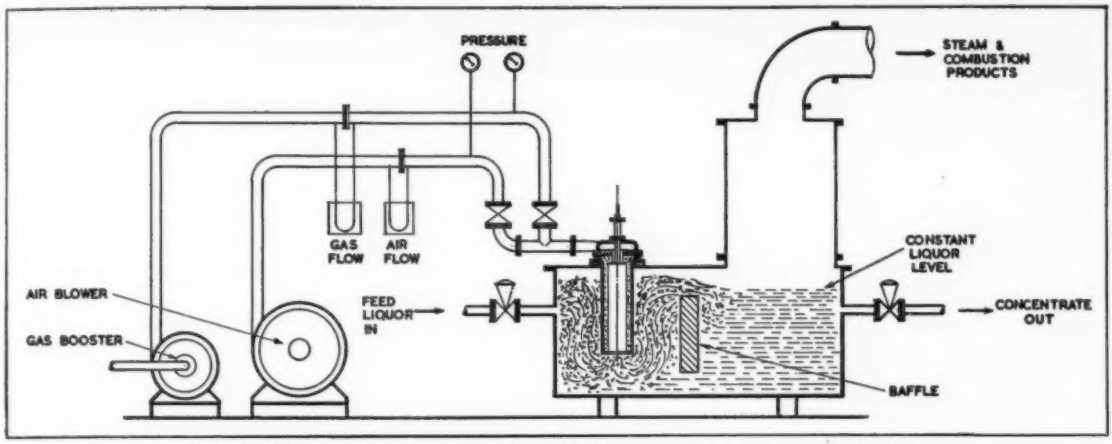


Fig. 1. Diagram of the submerged combustion evaporator in its simplest form.

the process. This heat loss is 10% of the gross heat value for coke-oven gas, but only 6% for fuel oil. The second heat loss is due to the inert gases which leave at the boiling point of the liquor. This loss thus depends on the boiling point and the volume of the gases. In order to minimise the volume, it is necessary that complete combustion should be achieved with the smallest possible excess of air.

Submerged gas burners have been developed which require as little as 5 to 10% excess air, while oil burners, even with heavy fuel oil, require only 50% excess air. Such burners reduce the loss due to inert exit gases to about 4% of the input heat, depending on boiling point and the particular fuel used. The only other heat loss is that due to radiation and convection from the plant surfaces. The burners, as Fig. 1 shows, are as close as possible to the liquor and the sole exposed surface is insulated by the ingoing air supply. It will be seen from this analysis of heat losses that nearly the maximum theoretical heat of the fuel is usefully employed. Heat efficiency is, in fact, higher than any other single-effect evaporation process starting with oil or gas as fuel.

In principle, it is possible to operate a submerged combustion evaporator as the first effect of a multiple-effect system. As far as the author is aware, no large-scale plant coupling a submerged combustion evaporator to a vacuum multiple-effect system has been constructed. However, several plants in Britain are equipped with pre-evaporators, the principle of which has been described by Swindin[2]. Such a unit, with details of its performance, is described later.

Table 1 compares the evaporation in different systems for the expenditure of 1 lb. of oil, assuming comparable conditions and hot feed liquor.

Avoiding Corrosion and Scaling

High thermal efficiency was not, as it turned out, the main factor in stimulating the development of submerged combustion. For its early history in this country we must look back to the Kessler concentrator of 1891, and the work in the 1920s of Swindin and Smith,[3] who were faced with the problem of heating a brine solution containing hydrochloric acid. This last work led to the first successful submerged burner in the chemical industry. It ran well for some years on a semi-production plant, under conditions which, at that time, made any other heating method impracticable. It was thus the absence of heat-transmitting materials which proved to be the significant advantage of the submerged burner.

TABLE 1.—Evaporation Obtainable for 1 lb. of Oil Fuel

System	Evaporation per lb. oil
Boiler and Single-effect steam	12.0
Boiler and Double-effect steam	22.0
Submerged combustion	15.5
Submerged combustion + pre-evaporator ...	22.3

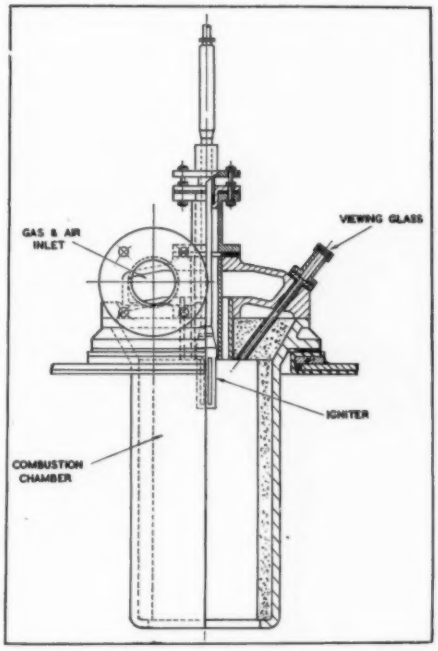


Fig. 2. Cross-section of a gas burner. The rate of heat release is 4 million Btu per cu. ft.

This trend in Britain to use submerged combustion evaporators mainly for corrosive solutions has persisted up to the present day. The only part of the evaporation plant exposed to the full corrosive attack is the dip tube which carries the hot gases down into the liquor. This small part may be constructed of a cheap material, such as cast-iron, and is regarded as a consumable item. Alternatively, it can be made of carbon or other expensive materials which

give a good life. The evaporator vessel may be fully protected by acid-proof brickwork.

In America submerged combustion evaporators were first used to avoid the fluctuating output and cleaning difficulties due to scaling of heat-transfer surfaces. The first large plant, commissioned in 1935, was for the dehydration of Glauber's salt. The inverted solubility of sodium sulphate leads to very heavy and rapid scaling in conventional steam-heated evaporators.

Intense Combustion

In order that the evaporation unit shall be as small as possible, it is necessary to minimise the size of the combustion chamber by burning the fuel at a very high intensity. Fig. 2 shows a gas burner in which the rate of heat release is 4 million Btu per cu. ft an hour. (See Reference 4 for comparison with other types of furnace.) To obtain this rapid rate of burning it is necessary to premix the gas and air in a special head, which also serves to insulate the top of the combustion chamber. The mixture then enters the chamber at a velocity above that of flame propagation. Lighting of the burner must avoid explosion and this is carried out by first igniting a pilot jet by means of a spark or low-voltage resistance igniter. The refractory lining of the chamber will withstand a flame temperature of over 1500°C, and this lining plays an important part in ensuring complete combustion. This gas burner is suitable for use with any gas except hydrogen which requires a special burner to allow mixing to take place in the combustion chamber itself.

The development of a suitable type of oil combustion chamber was undertaken about eight years ago, following experiments by Swindin. It was undesirable that oil-burning evaporators should be much larger than those burning gas, so a minimum combustion intensity of 1 million Btu per cu. ft an hour was specified. The designers achieved this high intensity, obtaining complete combustion even with heavy oils.[5] Unlike the gas burner, whose combustion chamber is about one-half submerged, the oil combustion chamber is mounted on the evaporator cover (see Figs. 3 and 4) and the hot gases are taken into the liquor by a dip-tube similar in design to the gas combustion chamber.

It is interesting to note that the high-intensity oil burner has now found numerous other applications outside the field of submerged combustion.[4] A recent survey[6] of submerged combustion in America suggests that oil-burning plant is not yet generally in use there.

Industrial Applications

Submerged combustion evaporation has now many applications in widely different industries. In America the original plant for sodium sulphate production has now been expanded to evaporate 150 tons a day. A feature of the natural gas burner used in this plant is the depth of its submergence in the liquid. Very large units of this type are in operation, some with a heat output of 30 million Btu an hour in a single burner. Other liquors concentrated by this type of burner are citrus fruit wastes,[7] potassium chloride, calcium chloride, phosphoric acid, spin-bath liquor, whey and magnesium chloride. The world's largest multiple-burner installation is for this latter application and has a heat input of 384 million Btu an hour. Submerged burners are also used as a source of inert gas, the heat being removed by submerging in water.

The carbon dioxide from submerged burners is extensively used in America for recarbonating water supplies which have been softened by the lime soda process. For this duty, a 10-ft depth of submergence is necessary to obtain good absorption of CO_2. In the 1940s another type

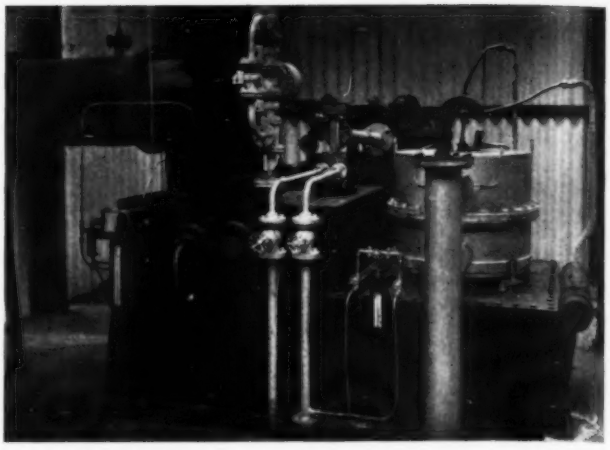


Fig. 3. Evaporator using an intensive oil burner as the source of heat. (Photo: Elkington Copper Refineries.)

of burner was widely used in America to heat steel pickling tanks. This burner did not premix gas and air, with the result that the combustion intensity was less than for other designs. Burning takes place in a pipe which extends to the bottom of the tank and then along its whole length. The hot gases bubble out from holes at intervals along the length of the pipe, causing both heating and violent agitation of the pickle. This agitation made possible much greater throughput of steel for a given pickling temperature. Burners of this general design have also been installed in Britain and Germany. The extremely corrosive conditions demand expensive materials of construction and units have been installed in Hastelloy C, and in some instances the conditions have been severe enough to employ a tantalum covering.

If hydrogen is available as fuel, submerged combustion is a highly efficient technique for concentrating caustic soda; a plant for this purpose is in operation in Canada.

In Britain the high heat efficiencies of submerged combustion were recognised, at least theoretically, in the late nineteenth century, and, at first, most effort was directed towards steam raising. This culminated in the announcement of a submerged combustion boiler in 1923.[11] It was not a commercial success, however, because no one wanted steam mixed with an almost equal volume of inert gas! In the late 1920s Hammond patented submerged combustion burners for several applications, including central heating of large buildings. A number of small units were installed, but these did not become established on a large scale.

Although the small unit of Swindin and Smith[3] had proved successful, it was not until 1946 that Swindin was again able to take up the development of submerged combustion in Great Britain. Since then it has become well established in several fields, including that of sulphuric acid concentration. The by-product acid from the manufacture of iso-propyl alcohol may be concentrated for recycling. Of three such plants, two have been designed for German companies. Several plants of up to 24 million Btu an hour are in operation concentrating process acid from 20 to 70% H_2SO_4. At present submerged combustion is not used above 78% H_2SO_4, since above this concentration the quantity of acid carried away by the gases increases sharply.

All large submerged burners concentrating sulphuric acid give rise to a small amount of acid mist in the gases; thus the plants incorporate suitable scrubbing equipment.

Wet-process phosphoric acid may be concentrated by submerged combustion up to nearly 60% P_2O_5. Since fluorine compounds are released during the concentration,

the evaporator and ducting are lined with carbon and the submerged burner dip-tube is of impervious graphite. The latest units operating in Europe include systems for the recovery of fluorine from the gases. With this wet-process acid, submerged combustion not only overcomes the corrosion difficulty but also allows crystallisation of calcium sulphate without scaling troubles.

In the detergent industry submerged combustion is used for concentrating trisodium phosphate solution, while the metallurgical industry uses a crystallising-type evaporator for the production of sodium tungstate. Another plant forms the final stage of a new process for concentrating coke-oven effluent. An interesting application exists in the fish meal industry, where concentrators are operating in Scotland, Norway and the Antarctic. These units take the fish or whale stick-water, a protein-rich solution of 6-8% solids, and evaporate to 45% solids. The concentrate may then be mixed with the meal before finally drying, so giving an enriched and larger yield of animal feedingstuff.

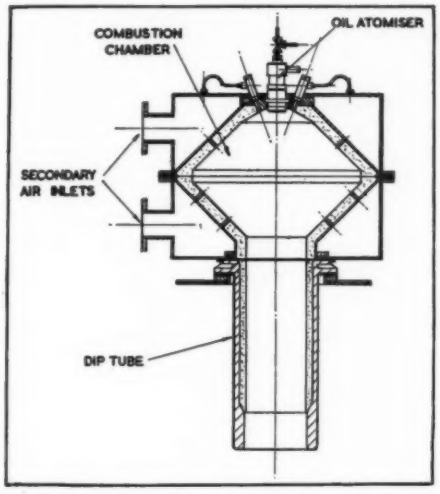


Fig. 4. Cross-section of burner shown in Fig. 3.

Treatment of Pickle Liquors and Titanium Oxide Process Effluent

Up to 12% of the sulphuric acid consumed in this country is used in the manufacture of titanium dioxide pigments. A further 5% is used for the pickling of steel. In these two industries about 400,000 tons of H_2SO_4 a year are converted into either ferrous sulphate crystals ($FeSO_4.7H_2O$) or into highly objectionable effluents. Effluent liquors from titanium oxide manufacture vary, but a typical composition is 25% H_2SO_4, 8% $FeSO_4$ (by weight). Most spent pickle liquors are about 10% H_2SO_4 and 17% $FeSO_4$. If these effluents are concentrated, the solubility of ferrous sulphate decreases until at about 50% H_2SO_4 its solubility is only 2%.[8] The ferrous sulphate thus separates, forming, under these conditions, crystals of monohydrate $FeSO_4.H_2O$, which can be separated from the acid. The free acid is then available for re-use in the case of pickling, or for further concentration in the case of titanium liquors.

Ferrous sulphate monohydrate, unlike copperas, $FeSO_4.7H_2O$, can be roasted to give SO_2 and ferric oxide, the SO_2 being reconvertible to sulphuric acid. Thus the effluent problem can be solved and wastage of raw materials prevented.[9, 10] In Great Britain the first stage towards this ideal, namely, recovery of the free acid and monohydrate, is now being operated.[9, 10] The concentration of a sulphuric acid with crystallisation of ferrous sulphate involves both corrosion and scaling tendencies, so it is not surprising that submerged combustion has proved particularly useful for this process.[12]

Fig. 5 is a basic flowsheet for a submerged combustion plant for concentration of spent pickle acid to 50% H_2SO_4 with separation of monohydrate. The weak liquor enters at about 80°C into the special heat exchanger, called the "pre-evaporator". This uses the heat from the evaporator exhaust gases by transmission through lead tubes, to the pickle liquor, which is circulated over the outside of the tubes. The temperature gradient for heat transfer is maintained not by vacuum operation but by evaporative cooling, wherein large volumes of air are drawn over the outside of the tubes. This evaporative cooling keeps the liquor at about 45°C on the outside of the tubes, the exhaust gases on the inside being saturated at 83°C at entry and leaving at about 60°C.

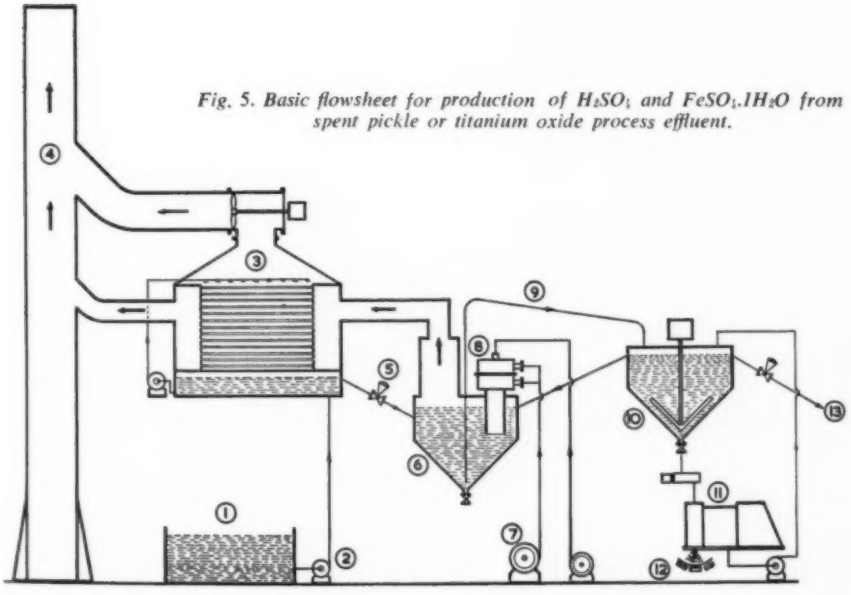


Fig. 5. Basic flowsheet for production of H_2SO_4 and $FeSO_4.1H_2O$ from spent pickle or titanium oxide process effluent.

Legend

1. Liquor storage tank.
2. Feed Pump.
3. Pre-evaporator.
4. Chimney.
5. Evaporator feed control valve.
6. Evaporator.
7. Air blower and oil pump.
8. Burner.
9. Air-lift pump.
10. Settler vessel.
11. Continuous centrifuge.
12. Monohydrate conveyor.
13. Acid production.

The pre-concentrated liquor, now nearly saturated with ferrous sulphate, enters the evaporator where the acid is maintained at 50% H_2SO_4, boiling at 110°C under submerged combustion conditions. Monohydrate crystals form in the evaporator and are removed continuously as a thin slurry. The slurry is delivered into a conical sedimentation vessel where the crystals settle, the excess of acid overflowing back to the evaporator vessel. Part of the acid is drawn off as production acid and is returned to the pickling process. The lower part of the settling vessel is fitted with a jacket to cool the thickened slurry before it is fed to a continuous centrifuge. This centrifuge is of the pusher type and is fitted with three coaxial baskets. Separation is effected by slotted sieves, while the crystal cake is pushed along from one basket to the next by the reciprocating motion of the first and third baskets relative to the second. During its passage through the centrifuge, the cake is washed with a small amount of warm water and emerges with about 2% of residual acid content.

The illustration on page 490 shows a two-unit plant of this type. The burner chambers, two to each evaporator, are for oil burning. Like all submerged combustion plants, these units are fitted with all the necessary safety devices to ensure that the burner gases cannot escape passing through the liquid. Throughput trials carried out on this plant (over 91 hours) under steady conditions made possible the operational data given in Table 2. These operating data show the capabilities of submerged combustion plants when evaporating "difficult" solutions. The second stage of this effluent problem, the conversion of the monohydrate to H_2SO_4, requires a monohydrate very low in residual acid and free water, and it is on the solids-separation side of these plants that development work is now proceeding.

TABLE 2.—Throughput Data for Submerged Combustion Plant Treating Waste Pickle Liquor (Mean Hourly Figures)

	lb./hr	Composition
Spent pickle	16,900	9.7% H_2SO_4, 16.5% $FeSO_4$
New acid added to replace $FeSO_4$ ...	2,340	78% H_2SO_4
Acid returned to pickling plant ...	7,150	42.7% H_2SO_4, 3.2% $FeSO_4$ (after slight dilution)
Monohydrate removed	3,000	2.4% H_2SO_4, 7% H_2O
Evaporation (total) ...	9,300	
Oil consumption ...	418	Gas oil
H_2SO_4 reclaimed ...	1,420	As 100% H_2SO_4

Evaporation per lb. of oil

Evaporator	14.0
Pre-evaporator	8.3
Total	22.3

Heat usefully employed per unit gross heat input = 1.37.

The author would like to express his thanks to Nordac Ltd. for permission to publish this paper; to the Steel Company of Wales Ltd. and Elkington Copper Refineries Ltd. for allowing use of photographs and operating data; and to the Institution of Chemical Engineers for permission to base the paper on a lecture given to the Graduates and Students Branch, Manchester Section.

REFERENCES

[1] Fairlie, A. M. "Sulphuric Acid Manufacture", Reinhold, London, 1936.
[2] Swindin, N. *Trans. Inst. Chem. Eng.*, **27**, 1949, 209.
[3] Swindin, N. *Trans. Inst. Chem. Eng.*, **5**, 1927, 110.
[4] Fraser, R. P. *Trans. Inst Chem. Eng.*, **35**, 1957, 219.
[5] Fraser, R. P. B.P. 703,914/1950.
[6] Cronin, C. S., *Chem. Eng.*, **2**, 1956, 163.
[7] Burdick, E. M., Anderson, C. O., and Duncan, W. E. *Chem. Eng. Prog.*, **45**, 1949, 539.
[8] Bullough, W., *et al. J. App. Chem.*, **2**, 1952, 703.
[9] Swindin, N. *Trans. Inst. Chem. Eng.*, **22**, 1944, 57.
[10] Pearson, J. *Sheet Met. Ind.*, June, 1951.
[11] Brunler, O. A., and McKay, D. M. B.P. 208,186.
[12] Swindin, N. B.P. 623,446. U.S.P. 2,616,790.

Demineralisation Developments

INCREASING DEMANDS FOR WATER for domestic, industrial and irrigation purposes are creating problems in water supply throughout the world, and novel sources of usable water are being sought widely. Investigations into the de-salting of sea water being conducted in Holland, now under the auspices of UNESCO, are at the stage when a pilot electrodialytic de-mineralisation plant for sea water is about to be put into operation at Scheveningen. In Britain a plant designed with the help of the Dutch Central Technical Institute and the British Department of Scientific and Industrial Research, which are co-operating in the UNESCO work, has just been completed by William Boby, Rickmansworth, Herts. Made for the Libyan Public Development and Stabilisation Agency, it will be installed in Tobruk for producing, at an economic price, potable water for domestic and agricultural use from brackish water with a high salt content. With water containing 5000 parts per million of salt, the plant produces potable water with, it is claimed, a consumption of only about 7 kWh of electricity for each 1000 gallons of water.

Permutit have been working independently on the problem of de-salting brackish water and are now building a pilot plant to run on a natural water containing some 3000 ppm of total dissolved solids (t.d.s.). When fed with this water the plant should deliver about 600 gallons an hour of treated water containing about 600 ppm of solids. The company plan to run the cell continuously for at least six months, and this test should bring to light any long-term difficulties that are not shown on laboratory-size units.

Sufficient data have already been obtained in the laboratory to enable the power requirements of an electrodialysis cell of the company's design to be estimated. The approximate values are stated in the following table:

T.D.S. of raw water (ppm)	kWh per 1000 gal.
2,000	9
4,000	15
8,000	25
12,000	33
20,000	50
33,000 (sea water)	72

Permutit claim that their design of equipment causes only a small back-pressure and that the pumping costs are only a small fraction of the power cost shown in the table. To the electrical costs must be added maintenance costs, capital depreciation, etc., and these can add from 50 to 100% on to the figures. A more accurate estimate of these other costs will be obtained from the pilot plant.

Improvements in both the membranes and the general design of the units will, in the view of the Permutit team, almost certainly reduce the overall cost of the treated water and, they hope, will also result in simplifications by the elimination of the acid dosing of the concentrated stream and the cathode compartment at present necessary to avoid scaling. In the meantime the 600-gallon-an-hour unit being built can be modified readily to deliver 1000 and possibly 2000 gallons an hour. This is a convenient unit-size from which to build plants for larger outputs. For plants very much larger than 10,000 gallons an hour a larger unit will be developed, and the appropriate number of these units used to give the required output. The use of basic units in this way is the most economical approach, since it is not practical to build a separate one for every job.

BRITISH PLASTICS CONVENTION

Summaries of selected papers presented at the Convention which was held recently in London in conjunction with the British Plastics Exhibition are given below

SOME ASPECTS OF LOW-PRESSURE POLYTHENE PIPES

*by Hermann Paul**

ONLY A MINOR PART of the output of low-density (high-pressure) polythene material has been processed as tubes. The high-density material has a higher bursting pressure, but its application involves several problems. The advantages of the high-density tubes are that they are easy to manufacture, light in weight and resistant to diluted acids and to soil acids. However, as the molecular weight increases the processibility decreases. Due to the inverse function of flow and other basic property characteristics, a compromise has to be found. One method is to work with mixtures of materials of high molecular weight containing small proportions of low molecular weight material.

The tubes prepared from high-density polythene with additions of carbon black and certain stabilisers of unpublished composition have great stability to sunlight. In general, they may be used to transport air, gas or diluted acids at normal ambient temperatures, that is up to 30 to 35°C, and pressures of up to 10 atmospheres. Under these conditions they will not change in structure. The recommended distance between holders is about 50 cm. Hot water may be transported but not under pressure. Although experience of this kind of tubing is not sufficient for a precise forecast of its life to be given, a life of at least 20 years can be expected. It has to be appreciated that the life of iron pipes used by water undertakings is 50 to 60 years. For the actual construction of pipework, threading of pipes is not recommended, except for temporary joints. For permanent joints a sleeve should be used of polyester resin which yields less than the main pipe. The latter is coated with a special adhesive and forced into a sleeve of slightly smaller dimension to produce joints that are stronger than the pipe.

In bacteriological tests, drinking water with controlled additions of bacteria were stored in tubes made respectively of polythene, iron and glass. The smallest increase in numbers of bacteria occurred in the iron pipe due to the bacterio-static action of copper and zinc in the iron. It had proved possible to incorporate small amounts of these elements into the polythene, producing a tube with bacterio-static properties yet harmless to human beings. This modified polythene was still under test.

SOME RECENT DEVELOPMENTS IN EXTRUSION

by A. Kennaway†

AT THIS STAGE we are well below the limit of extruder output, which can be increased provided that the polymer is made to absorb the mechanical energy of the motor. If this suggestion is confirmed, novel and very simple fast-running extruders will result. It had been possible in trials to extrude 45 lb/hr from a barrel of $\frac{5}{8}$-in. diameter running at 5000 rpm. Experimental and theoretical work has been carried out to help in laying a basis for the design of extruders and dies. Little mixing occurs in the unmodified extruder, as was demonstrated in a cine-film of a model of a screw working in glycerine using poppy seeds to show flow. (The model in perspex which had been filmed was available for demonstration at the lecture.) Irregularities in the flow and consequent poor mixing could be improved by using long conical dies with an included angle of about 15 degrees. Square-edged dies or those with a wide taper produced rough surfaces at increasing speeds.

A simplified heating and cooling system had been developed which dispensed with the need for electronic controls and provided simple and accurate temperature control of the melt under both endothermic and exothermic conditions. This consisted of a sectioned jacket, containing liquids boiling under reflux, with electrical heating using relatively cheap energy controls. By suitable choice of liquids desired temperatures could be obtained.

Part of the screw channel remained empty and this gave the volatiles the opportunity to escape readily from the extruder. This process could be improved by increasing the volume available and there were several methods of doing this. For example, by screws of Dupont, Hartig, the National Rubber Manufacturing Co., as well as by the twin screws of the Welding Engineers Inc.

RECENT ADVANCES IN FLUORINE POLYMERS

by G. W. Bowley†

ALTHOUGH THERE IS now available a considerable range of fluorine polymers, most of them must still be classed as development products. Polytetrafluoroethylene (P.T.F.E.), on the other hand, is now a well-established material. The earlier granular polymer still remains the most important form, but the more recent dispersion polymer is likely, within the next two or three years, to assume the leading role. In coagulated or paste form, dispersion polymer has been developed to give extrusions remarkable for their excellent flexural fatigue behaviour. The two most important uses are for wire and cable insulation and as linings for high-pressure flexible hose. The world consumption of fluorine polymers is approaching 2000 tons a year, of which over 90% is P.T.F.E., most of which is used in the U.S.A. The main "snag" in using it for chemical plant is the difficulty of finding an adhesive with the same chemical resistance as the polymer. It has potentially a wider range of application than other plastics and its future appears bright, but until some of the fundamental limitations of the other fluorine polymers have been overcome their future is less certain. One rather unexpected use is in the manufacture of high-grade steels which forms a market for scrap P.T.F.E. At the rate of 2 to 8 oz. a ton of steel, it is used as a degassing agent and results in considerable savings. For example, in aircraft castings it reduces the number of cracks in the castings.

* *Chemische Werke, Hüls.*
† *Imperial Chemical Industries Ltd., Plastics Division.*

LIQUID ATOMISATION IN CHEMICAL ENGINEERING*: PART 2. ROTARY ATOMISERS

by R. P. FRASER, O.B.E. M.I.Chem.E.,
E. P. EISENKLAM, Ph.D., M.Eng.Sc., and
N. DOMBROWSKI, Ph.D., A.M.I.Chem.E.†

In this section of their series the authors deal with rotary atomisers, their applications, design features and operating principles. Drop formation and drop sizes are also considered

THE rotary atomiser utilises centrifugal force to accelerate liquid to such a velocity that the cohesive surface tension and viscous forces are overcome and disruption takes place. Since the accelerating force can be independently controlled, this type of atomiser, in the same way as the twin-fluid or blast atomiser, is extremely versatile. It can handle successfully a wide range of feed rate with liquids having a wide range of property, from thin solutions to highly viscous gels or slurries.

The wide variety of existing designs can be classified into three groups:

(1) Flat discs (Fig. 1 (a)).
(2) Bowls or saucers (Fig. 1 (b)).
(3) Vaned discs or slotted wheels (Fig. 1 (c)).

In each classification the diameter may vary from 1 in. to 18 in. with rotary speeds up to 60,000 rpm. Disc speeds for diameters of 1 ft and upwards are of the order of 12,000 rpm, and such large discs have capacities for feed liquor of more than 5 tons an hour.

When highly viscous liquids are being atomised, it is advantageous to use spinning bowls in conjunction with an additional gas blast around the periphery for further atomisation (see Fig. 1 (d)). Under these conditions, the task of the disc is to film the liquid so that the energy transfer between gas and liquid can occur with high efficiency.

Design features, in the main, are concerned with efficiently transmitting energy to the liquid, so that the disrupting forces are at a maximum when it leaves the atomiser.

Liquid Flow in Rotary Atomisers

When liquid is centrifuged from the centre of a rotating surface, its velocity at any point on the surface may be resolved into a radial and tangential component. For a frictionless liquid, the radial velocity at any point is equal to the tangential velocity at that point, i.e., πND. The resultant velocity is therefore equal to $\sqrt{2}\pi ND$, and the maximum energy imparted to the liquid is given by $m\pi^2N^2D^2$;

where m = mass flow rate;
N = rotary speed; and
D = rotor diameter.

The theoretical power required to produce this energy can thus be written as

$$\text{Power } P = 42.5 \times 10^{-12}\, m\, N^2 D^2 \text{ horse-power} \quad \ldots.(1)$$

where m is in lb./hr, N in rpm, and D in ft.

This relation is plotted in Fig. 2 and shows the power per unit mass flow rate as a function of disc diameter and speed.

At low speeds and feed rates, when there is no slip, the tangential velocity of the liquid leaving a rotating surface is equal to its peripheral velocity. At rotary speeds and feed rates greater than approx. 1000 rpm and 4.2 lb./hr respectively, polished flat discs do not impart maximum tangential velocity because of slip between the disc surface and the liquid, although this loss in velocity is reduced with increase of disc diameter. They are therefore unsuitable for efficiently atomising liquids at practical flow rates. Slip is considerably reduced with saucer- or bowl-shaped discs where the liquid is being continually forced against the rotor surface, but above a critical flow rate per unit wetted perimeter, slip tends to increase. The conditions for severe slip occur when the value of the relation

$$\frac{m}{\eta \pi D} \text{ is greater than } 1440$$

where m = mass flow rate, lb./hr;
η = viscosity, cp.; and
D = disc diameter, ft.

† **Mr. R. P. Fraser** was educated at Kelly College, Tavistock, and graduated in chemistry at the Imperial College of Science in 1923. He became one of the first students under Professor W. A. Bone, Fuel Technology Department. Since 1940 he has been directing research at the Chemical Engineering Department of the Imperial College on many problems relating to high-speed fluid flow and, since 1946, on the atomisation of liquids.

Dr. P. Eisenklam graduated from Melbourne University in 1945 with honours in mechanical engineering. In 1950 he joined the staff of the Chemical Engineering Department of Imperial College as Senior Research Assistant and is now Special Lecturer.

Dr. N. Dombrowski was educated at the Cambridge and County High School and Imperial College, from which he graduated in Chemical Engineering. He obtained his doctorate at Imperial College for research into the fundamentals of liquid atomisation.

* *Part 1 of this series was published in the August issue, page 414.*

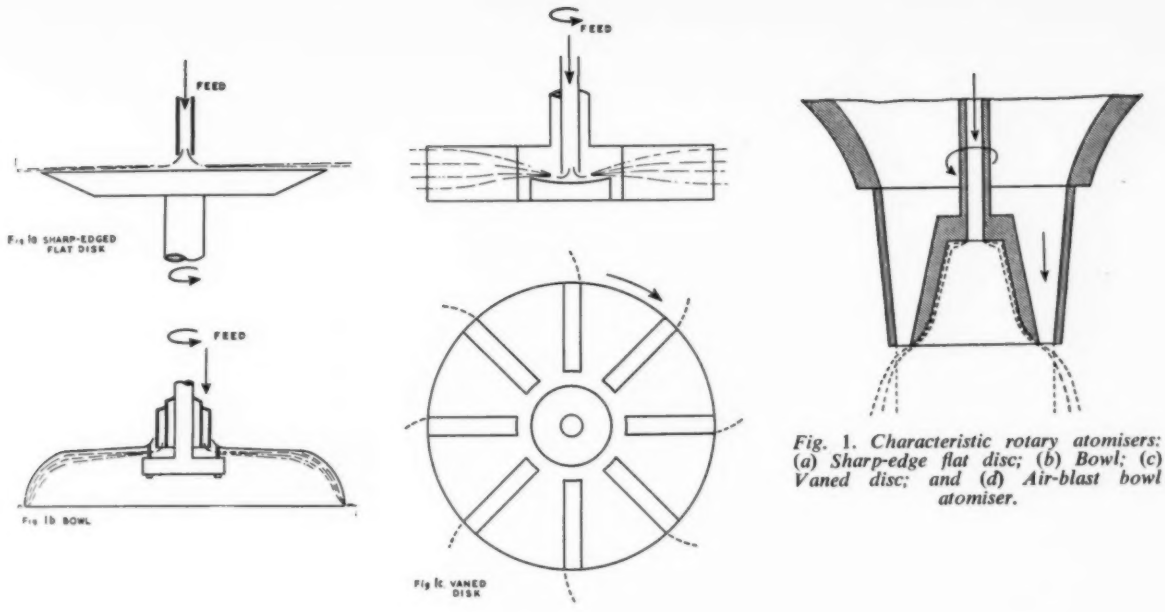


Fig. 1. Characteristic rotary atomisers: (a) Sharp-edge flat disc; (b) Bowl; (c) Vaned disc; and (d) Air-blast bowl atomiser.

For example, with a particular 5-in. diameter disc spraying water at the rate of 500 lb./hr, the water has a peripheral or tangential velocity of approximately 0.8 of that of the disc. If the flow rate is increased to 5000 lb./hr, the water velocity falls to less than half that of the disc.

Slip can be completely eradicated by constructing the disc with radial vertical vanes so that the liquid is forced against the leading edge of each vane. Although this design is more efficient, it is more complicated and more difficult to balance dynamically. Care must also be taken to ensure that impeller action is at a minimum, otherwise considerable power may be wasted in pumping air. This type of design is unsuited to erosive liquids, since severe erosion is caused as the liquid impinges on the rear edge of the vanes. With spinning bowls, erosion can be minimised by placing relatively cheap expendable liners over the main bowl.

The radial velocity at the periphery of a disc is given by the relation

$$V_R = 0.043 \left[\frac{\rho N^2 Q^2}{\eta D}\right]^{\frac{1}{3}} \text{ for bowls} \quad \ldots . (2)$$

$$= 0.043 \left[\frac{\rho \pi^2 N^2 D Q^2}{\eta b^2 n^2}\right]^{\frac{1}{3}} \text{ for vaned discs} \quad \ldots . (2a)$$

where N = rotary speed, rpm;
V_R = radial velocity, ft/sec.;
ρ = liquid density, lb./cu. ft;
Q = volume flow rate cu. ft/min.;
η = viscosity, centipoise;
b = height of vane, ft;
n = number of vanes; and
D = disc diameter, ft.

The radial velocity is an inverse function of the wetted periphery and liquid viscosity, and a direct function of the rotary speed and total flow rate. The two equations are identical when the total wetted perimeter of the vanes is equal to the periphery of the bowl. The relation has been plotted in Fig. 3 for a 6-in. diameter disc spraying water at 10,000 rpm.

The figure also shows the effect of mass flow rate on the mean drop size of the spray (based on Equation (4)), and the angle at which the liquid leaves the edge, assuming that it is fully accelerated to the peripheral velocity of the disc.

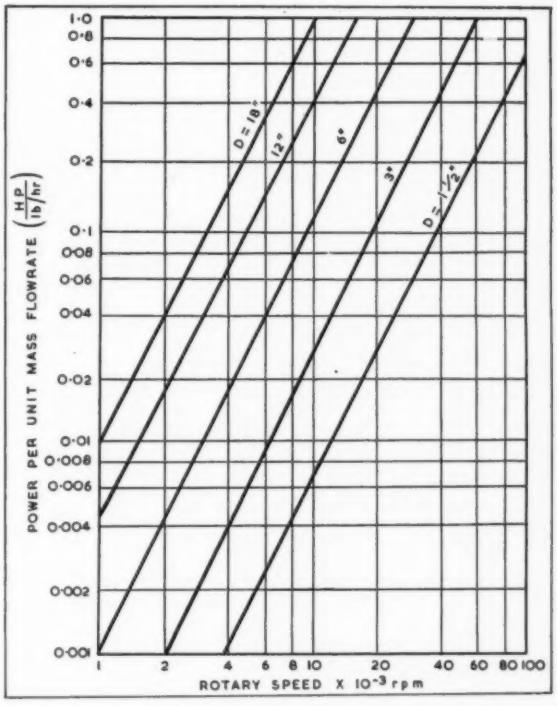


Fig. 2. Theoretical power requirements above no-load conditions for various diameter discs and rotary speeds.

For example, at a feed rate of 40 lb./hr, the liquid has a radial velocity of 5 ft/sec., and drops of 75 microns mean diameter are centrifuged at an angle of approximately 1° to the tangent. At a feed rate of 4000 lb./hr, the corresponding values are 100 ft/sec., 190 microns and 22° respectively. It can be seen that large radial velocities only occur at excessively large flow rates. Under normal operating conditions, the radial velocity is much less than the tangential velocity, and the liquid is therefore centrifuged almost tangentially from the periphery.

Processes of Drop Formation from Rotors

The manner by which drops are produced from rotary atomisers depends on the disc diameter, the rotary speed, the efficiency of energy transmission from the rotary member to the liquid, the liquid flow rate and its surface tension, viscosity and density, and finally on the degree of wetting of the surface. Atomisation occurs when surface tension and viscous forces are overcome by centrifugal forces, and at high peripheral velocities this process is aided by air friction. Three stages of drop formation can be distinguished.

In the first stage, liquid fed at a small rate near the axis of the rotor spreads out towards the periphery where it forms a stationary toroidal ring. As liquid continues to flow into the ring, its inertia increases and overcomes the restraining surface tension. Disturbances appear on the outer edge and grow in size until liquid is centrifuged off as discrete drops. This process can be seen in selected frames of a high-speed cine strip in Fig. 4. The arrow shows the history of such a disturbance. As the disturbance grows in size and extends from the rim, it commences to draw itself into a spherical globule which remains attached by a fine attenuating thread. When the drop is finally detached, the retaining thread breaks down into a chain of small or satellite drops. The liquid adjacent the rim of the disc tends to be drawn back into the toroid, but is prevented by incoming liquid and the process is repeated.

The second stage of drop formation, seen in Fig. 5 (a), occurs when the feed rate is increased. The retaining thread grows in thickness and, resulting from the longer time of break-down, forms long jets. Whereas the first stage of drop formation is essentially an intermittent process, atomisation is now fairly continuous with the jets uniformly distributed around the whole periphery. The uniformity of diameter of the threads depends upon the peripheral velocity and becomes more uniform as the velocity is increased.

The shape of jets requires some explanation, since their profile is not necessarily caused by air friction. The path of a liquid particle relative to the ground is a straight line. Its direction depends on the relative magnitudes of the radial and tangential velocities. Since the atomiser is rotating, the particle trajectory or path, relative to the atomiser as seen by a camera, is of involute form.

Fig. 6 illustrates the involute as a function of the radial/tangential velocity ratio. It shows that the angle to the tangent at which the liquid leaves the disc increases from zero to 45° as the radial velocity is increased to the value of the tangential velocity. However, the corresponding change in the trajectory is very much smaller.

With further increase of flow rate, the jets are unable to remove all the liquid, the ring is forced away from the periphery and a thin sheet extends around the disc. The mechanism by which this sheet breaks-down depends on the liquid properties, rotary speed and ambient conditions. Fig. 5 (b) shows the break-down of an oil/water emulsion, where small holes suddenly appear in the sheet as it advances into the atmosphere. They rapidly grow in size, until the thickening rims of adjacent holes coalesce to form threads of varying diameter. The threads finally break-down into drops. If the liquid is a solution, a new ring is formed in the atmosphere away from the periphery of the disc and drops are produced in a similar manner to stages 1 and 2 (Fig. 5 (c)). However, since the ring is not fixed by a solid surface, it is quite irregular and this results in an irregular formation and size of threads.

At high peripheral velocities (Fig. 5(d)), the sheet is disintegrated by air action. Holes and tears appear on the sheet, and the resulting fragments are rapidly atomised as they start to contract into threads. With increase of rotary speed, the region of disintegration recedes back

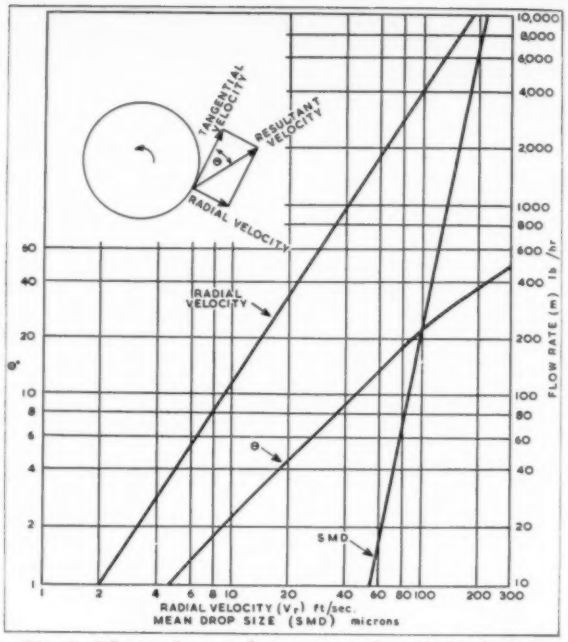


Fig. 3. Effects of mass flow rate on the radial velocity, path and drop size of liquid sprayed from a 6-in. diameter disc rotating at 10,000 rpm (peripheral velocity 262 ft/sec.).

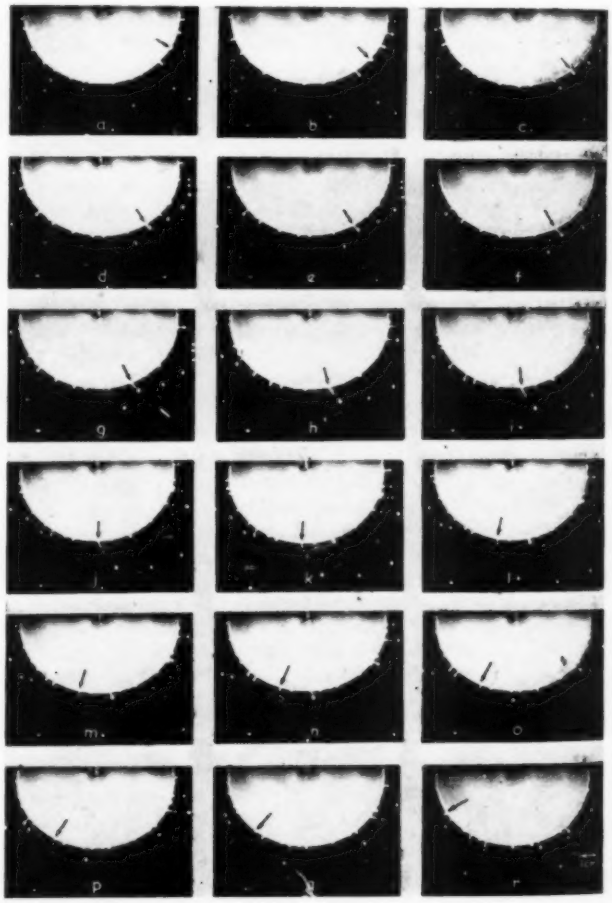


Fig. 4. Process of formation of drops of uniform size from a spinning disc atomiser (a-r).

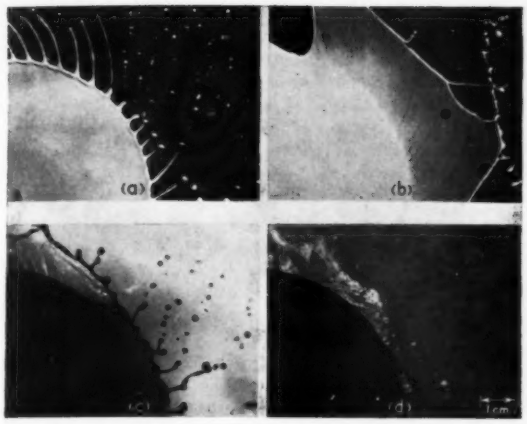


Fig. 5. Drop formation from a spinning disc atomiser (a-d).

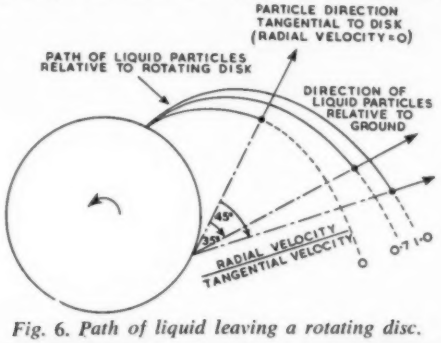


Fig. 6. Path of liquid leaving a rotating disc.

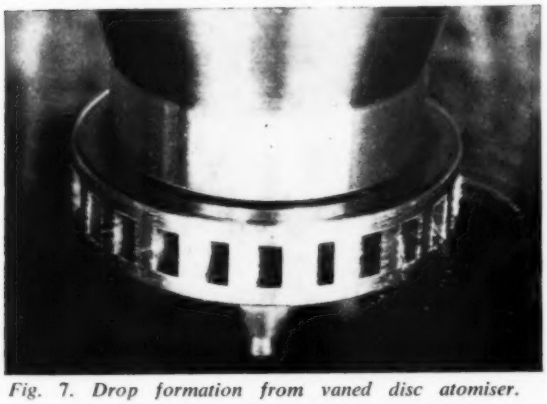


Fig. 7. Drop formation from vaned disc atomiser.

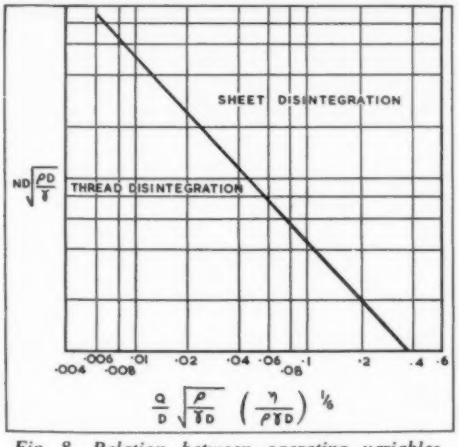


Fig. 8. Relation between operating variables and mechanism of distintegration.

towards the disc, and thus an approximately constant sheet thickness is maintained at break-up.

Although the manner of disintegration described above is for flat discs, the same processes occur with bowls and vaned discs. Fig. 7 illustrates the second stage of thread formation with the latter type. It shows that streams of threads are produced from films formed on the leading vertical surfaces of each radial vane

Since stages 1 and 2 can result in a spray of uniform drop size, while stage 3 produces a heterogeneous spray, it is of interest to examine the conditions governing the transition from the stages of thread to sheet formation. For flat discs and bowls, assuming no slip between the liquid and the surface, and a small radial velocity relative to the tangential velocity (a condition usually met in practice), the transition is a function of the dimensionless parameters

$$ND\sqrt{\frac{\rho D}{\gamma}} \text{ and } \frac{Q}{D}\sqrt{\frac{\rho}{\gamma D}}\left(\sqrt{\frac{\eta}{\rho\gamma D}}\right)^{\frac{1}{3}}$$

where N = rotary speed;
D = disc diameter;
ρ = liquid density;
γ = surface tension;
Q = volume flow rate; and
η = viscosity.

The approximate relation between them is shown in Fig. 8. There is insufficient evidence to decide whether the relation is valid for vaned discs, but there is no reason why it should not apply. If it is assumed to be valid, the value of D in the fraction Q/D should be replaced by the diameter of that circle whose periphery is equivalent to the wetted periphery of all the vanes.

Drop Sizes Produced from Rotary Atomisers

The mean drop size, defined as surface mean diameter, is the diameter of a drop with the same surface-volume ratio as the whole spray cloud. It increases with increased liquid flow rate, viscosity and surface tension and diminishes with increased rotary speed, disc diameter, wetted periphery and liquid density. The relations depend on the operating conditions. Discs operating at low feed rates of 30 lb./hr, and forming a wide drop spectrum at the periphery through stages 1 and 2, can be made to produce homogeneous sprays if the drops are separated in sizes by gravity. An example of the degree of separation that can be obtained is illustrated in Fig. 11 for various feed rates. It shows the drops collected at various distances from a disc situated to the left of the picture and demonstrates that the proportion of the smaller satellite drops increases with feed rate until they constitute a considerable proportion of the total cloud.

Under these conditions, the maximum drop size obtained for sharp-edged discs is given by

$$d_m = \frac{45.5 \times 10^4}{N}\sqrt{\frac{\gamma}{D\rho}} \text{ microns} \qquad \ldots . (3)$$

where d_m = maximum drop size, microns; and
γ = surface tension, dynes/cm.

These values are approximately 13% lower than those obtained from flat-edged discs, but the differences are minimised as peripheral velocities are increased to values greater than 42 ft/sec.

At higher and more practical feed rates, and especially with high peripheral speeds, turbulent air streams entrained around the disc inhibit a clean separation. Because of difficulties involved in sampling dense clouds of heterogeneous liquid drops, formulæ relating their sizes to the operating variables are only approximate and vary from one worker to another.

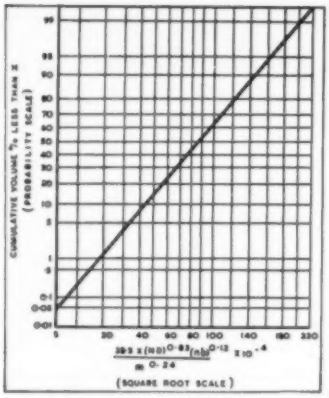


Fig. 9. Drop size distribution.

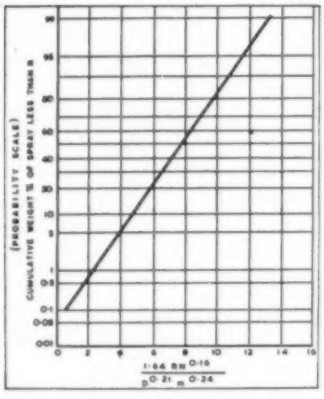


Fig. 10. Cumulative weight per cent of total spray collected at different distances (R) *from disc.*

One formula which correlates data over a wide range of variables can be written as:

$$SMD = 4.2 \times 10^4 (1/N)^{0.6} (1/\rho)^{0.5} \left(\frac{\eta_l m}{D}\right)^{0.2} (\gamma/x)^{0.1} \quad \ldots . (4)$$

where SMD = surface mean diameter, microns;
N = rotary speed, rpm;
n = number of vanes;
b = height of vanes, ft;
m = mass flow rates lb./hr;
D = disc diameter, ft;
ρ = liquid density, lb./cu. ft;
γ = surface tension, dynes/cm.; and
x = wetted periphery, ft
$= \pi D$ for flat discs and bowls,
$= nb$ for vaned discs.

This equation is valid for the following operating range:
D = 0.17-0.67 ft;
N = 860-18,000 rpm;
m = 33-4050 lb./hr;
γ = 74-100 dynes/cm.;
ρ = 62.4-88 lb./cu. ft; and
η_l = 1-9000 cp.

The maximum drop size for a very wide range of flow rates is approximately three times the mean drop size as given by Equation (4). The equation shows that, for a given liquid, the most important factors influencing the drop size are the rotor speed and diameter. The length of wetted perimeter has a relatively small effect. While the wetted perimeter for a disc or bowl is fixed by its diameter, that for vaned discs can apparently be varied by altering the total number and height of the vanes. This is not very practical, however, since it becomes increasingly difficult to wet the whole vane height and the total number cannot be increased indefinitely, since the resulting smaller vane lengths would inhibit complete liquid wetting. It is also of interest to note from Equation (2a) that the radial velocity is reduced as the total wetted periphery is increased.

Information on the total drop size distribution has only been obtained for water as the sprayed liquid, but the results are probably more accurate than those given in Equation (4). Fig. 9 shows these results, accurate to ±25% plotted on square-root—normal probability. These results are valid for vaned discs containing 8-24 vanes, with heights ranging from 0.026 to 0.11 ft, diameters from 0.17 to 0.67 ft, speeds from 5000 to 32,500 rpm and feed rates from 12 to 3000 lb./hr. The results can be utilised for bowls or flat discs by substituting the correct wetted periphery "πD" for "nb".

Drop Penetration in the Atmosphere

With pressure nozzles and blast atomisers, the spatial distribution of the resulting spray cloud can, within certain limits, be reasonably controlled. In rotary atomisers, except where a peripheral air blast is employed (Fig 1 (d)), there is no control of the drop cloud after it has left the periphery.

A rotary atomiser with a vertical axis ejects drops in a horizontal direction. The drops soon decelerate by air friction and begin to fall under gravity. Small drops will decelerate earlier than large ones and thus fall away nearer the atomiser. Under still ambient conditions it is thus pos-

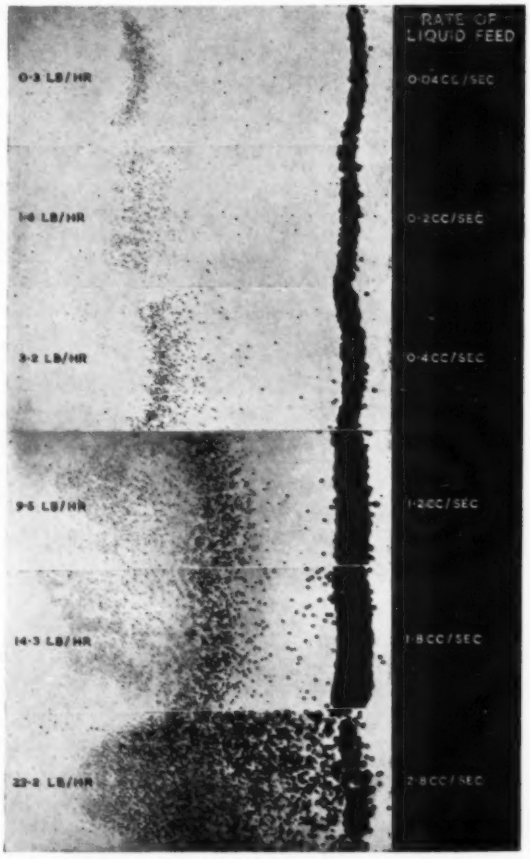


Fig. 11. Illustration showing the effect of rate of liquid feed on drop spectrum.

sible to deposit a spectrum of drops continuously, ranging from small sizes near the rotor axis to large sizes away from it. By placing slits at various radial positions, spray clouds consisting of uniform drop sizes can be collected. These conditions accrue with flat discs operating at low feed rates. At high feed rates and more complex disc designs, air entrainment creates turbulent air streams which carry small drops farther away so that the continuous spectrum is disturbed and the various sizes are mixed.

The size and distance of projection of a drop depend on its initial velocity of ejection. As the rotary speed is increased, the drop gains further momentum and is projected farther away. However, since the drop diameter is an inverse function of the rotary speed, drag forces increase until, at a critical diameter, a maximum distance is reached. Whereafter, the distance is progressively reduced even though drops have greater initial velocities. The distance of projection is also a function of the feed rate. An increased liquid flow increases the drop diameter and thus its path in the air.

The surrounding atmosphere plays an important role in determining the final spatial distribution of the drops. Since all discs have an air impeller action to a greater or lesser degree, it is not possible to correlate the distribution with rotors of differing design, and it is necessary to determine the distribution for each design.

The relation between the weight distribution of water produced from radial-vaned discs and the operating variables is given in Fig. 10, which shows the cumulative weight per cent at any radial distance, R ft, 3 ft below the plane of the atomiser. The relation is valid for feed rates ranging from 600 to 3000 lb./hr, disc diameter 0.31 to 0.67 ft and rotor speeds from 1500 to 9800 rpm. It is independent of the number and height of vanes within the ranges 8 to 24 and 0.03 to 0.11 ft respectively.

The radial distance, R_{max}, at which 99% of the spray falls 3 ft below the plane of the disc, is given by:

$$R_{max} = \frac{7.2 D^{0.21} m^{0.2}}{N^{0.16}}$$

Rotary atomisers, compared with pressure nozzles, are characterised by a high degree of drop size uniformity when operating at low feed rates. Under practical operating conditions, however, where large flow rates and high rotary speeds are used, their drop sizes and distribution become comparable.

(Part 3 in this series will be published in the October issue.)

INDEX OF NOMOGRAMS, 1956

by O. P. Kharbanda, D.Ch.E., A.M.I.Chem.E.

This Index of Nomograms has been prepared from the more important journals publishing nomograms of interest to the chemical engineer.

TABLE OF JOURNALS CONSULTED

Journal	Abbreviation	Vol. No. for 1956
Angwandte Chemie	A C	68
British Chemical Engineering	B C E	1
Chemical Engineering	C E	63
Chemical and Engineering Science	C E S	5
Chemical and Process Engineering	C P E	37
Chemie-Ingenieur-Technik	C I T	29
Coke and Gas	C G	18
Industrial Chemist	I C	32
Industrial and Engineering Chemistry	I E C	48
Journal of Chemical Education	J C E	33
Journal of Institute of Petroleum	J I P	42
Journal of Research National Bureau of Standards	J R N B S	56
Petroleum Refiner	P R	35

INDEX
(Arranged Alphabetically by Subject)

Combustion calculations, five charts	*Kist and Frumerman*	C E July. 179
Combustion calculations, obtaining various values from Orsat analysis	*Mekler and Ungar*	P R June. 157
Combustion, coal, ash, % combustibles	*Mapstone*	C E March. 212
Combustion, gas composition in rich	*Luft*	C E May. 212
Conversions, wt. % → mol. % —→ vol. %, binary mixtures	*Voorwijk*	C E May. 201
Conversions, wt. % → mol. %, ternary mixtures	*Lessels*	C E July. 208
Cost analysis, "Econograph" for	*Gaffney*	P R Aug. 111
Critical volume, estimation	*Kharbanda*	I C Oct. 474
Density, aqueous solutions of nitric acid	*Kharbanda*	I C Oct. 412
Density, aqueous solutions of sulphuric acid	*Kharbanda*	I C July. 264
Density, liquid, from Tc and one density value	*Osborn*	C E March. 196
Distillation, batch, number of plates, R.R., hold-up	*Houtman and Husain*	C E S —. 185
Distillation, bubble-cap plate columns, liquid capacity	*Walsh and Lafyatis*	C E April. 193
Enthalpy of various common gases 32-3000°F	*Younger*	C E Nov. 209
Equilibria in carbonate ammonia solutions	*Kharbanda*	C G April. 139
Extraction, $P = 100\ (E-1)/(E^{n+1}-1)$	*Davis*	C E Oct. 222
Flashing, vapour yields on	*Grosberg and Mapstone*	P R April. 208
Fluidisation velocity, $Dp, \mu, \frac{}{\rho v}$	(Abstract)	C I T —. 231
Gas, flow rate in circular ducts	*Cichy*	C E Feb. 204
Gas, flow rate through orifices and nozzles	*Gibbons*	C E July. 204
Gases, water content of (circular computer)	*Diniak and Weaver*	J R N B S —. 269
Heat exchanger, modular, sizing and L.M.T.D.	*Callard*	C E July. 197
Heat exchanger, tube and shell, design estimate	*Auro and Andres*	C E March. 208
Heat exchanger, tube and shell, leakage factor	*Fabregas*	C E April. 181
Heat transfer equation, $Q = UA\Delta t$	*Flynn*	C E Jan. 220
Investment, justification of detailed estimate	*Winn*	P R July. 199
Mixtures, three comp., graphical solution for	*Vera*	C E April. 210
Natural gas, hydrocarbon liquid content of, "charcoal weight test"	*Crawford*	P R April. 166
Nomograms, design your own	*Purchas*	B C E May. 39
Nomograms, preparation of different type	*Winn*	{ P R Feb. 121 / P R March. 171
Orifice, sizing and pressure drop	*Troupe and Goodwin*	C E Oct. 199
pH, temperature correction for, 20-170°C	*Ingruber*	I C Dec. 518
P-V-T data, Freon-142, Monochloro difluoro-ethane	*Davis*	C E Nov. 232
Packed column, pressure drop and diameter	*Jacobs*	P R June. 187
Petrol, yield from crudes	*Prater*	P R May. 236
Pickling liquor, quick estimation of $FeSO_4$ in	*Kharbanda*	B C E Nov. 384
Plate, bubble - cap, liquid gradient	*Rodriguez*	C E Nov. 230
Pump, cost of pumping	*Hicks*	P R Dec. 234
Pump, horse-power	*Macdonald*	B C E Oct. 300
Pump, reciprocating, capacity of	*Macdonald*	B C E Oct. 301
Reynolds number	*Purchas*	B C E Oct. 329
Solubility, SO_2 in H_2O	*Davis*	C P E Dec. 420
Standard deviation	*Davis*	C E April. 206
Thermal conductivity, aqueous NaOH and KOH	*Kharbanda*	I C April. 157
Vacuum system problems, orifice diameter	*Greenhalgh and Miller*	C E Jan. 222
Vapour pressure, aqueous diethylene glycol	*Davis*	C E Aug. 232
Vapour pressure, chlorinated solvents	*Holland and Davis*	C E May. 210
Vapour pressure, gasoline	*Mapstone*	J I P March. 95
Vapour pressure, phosphoric acid	*Kharbanda*	I C March. 120
Venturi, breakpoint pressure	*Wright*	C E Nov. 221
Viscosity, hydrocarbons 1-20 C atoms	*Lohrenz*	P R Nov. 169
Viscosity, lubricating oil blends	*Davis*	C E March. 214
Weight, correction for air temperature	*Riehl and Ortmann*	A C —. 516
Weir, height of liquid over	*Rodriguez*	C E Nov. 230

SELECTION OF COOLING TOWERS AND AIR-COOLED HEAT EXCHANGERS

This article compares economically the two main types of cooling equipment and presents in simple, graphical form a means of selection for any particular project

by EDWARD B. TALBOT,* B.Sc.(Chem.Eng.), A.C.G.I., and DEREK J. TOW,† B.Sc.(Eng.), Dipl.Chem.Eng., A.M.I.Mech.E., A.M.I.Chem.E.

AIR-COOLED heat exchangers (Fin-fans) can be used instead of cooling towers plus heat exchangers. This means that the process fluid can be directly cooled in an air-cooled heat exchanger (Scheme A) or indirectly cooled by means of cooling water in a normal heat exchanger (Scheme B).

The Balancing Factors

A very extensive report on these two main methods of cooling was prepared some years ago for a Government department.[1] This report showed that very approximately the capital cost of an air-cooled heat exchanger is of the same order as the capital cost of a comparable cooling tower and heat exchanger system. It also showed that the power cost of the air-cooled heat exchanger is greater than that of the cooling tower. These two factors will, however, be constant for any given installation. This, therefore, leaves two further factors to be considered in an economic comparison, which, although relatively small quantitatively compared to the cost of the main items of equipment, are, however, the balancing factors when establishing the most appropriate solution. These items are:

(1) the cost of the cooling tower make-up water; and

(2) the pipework and pumping cost for interconnecting the cooling tower, heat exchanger and the make-up water supply.

It will be obvious that in very arid regions make-up water will be in short supply and thus very expensive, and in these conditions air-cooled heat exchangers would be used. This is particularly the case in Central America and the Middle East on such installations as natural gas and crude-oil transmission compressor stations. In other areas, although a water supply may be available, it may be necessary to pipe the water over a long distance, and this would lead to expensive piping and pumping costs. These thoughts underlie the basic idea of arranging the curves in Figs. 1 and 2 in such a form that make-up water and pipework and pumping costs could be readily considered in relation to the whole scheme.

It will be seen that two curves are involved. Fig. 1 relates make-up water costs to the pipework and pumping costs of a conventional cooling tower/heat-exchanger system. In order to make the curves as general as possible, and to reduce to a minimum the influence of interest and depreciation rates, the pipework and pumping costs have been expressed as a percentage of the annual capital charge on the cooling tower/heat-exchanger system. Curves were plotted for varying power costs between ½d. and 2d. a unit, and all these lines fall relatively close together. This shows quite conclusively that power cost is not a decisive factor when comparing the use of air-cooled heat exchangers with cooling towers plus heat exchangers.

It will be noticed that the vertical axis on Fig. 1 is for a make-up water cost factor and not the direct cost of make-up water. This has been done because it was found that substantially similar curves were obtained when the

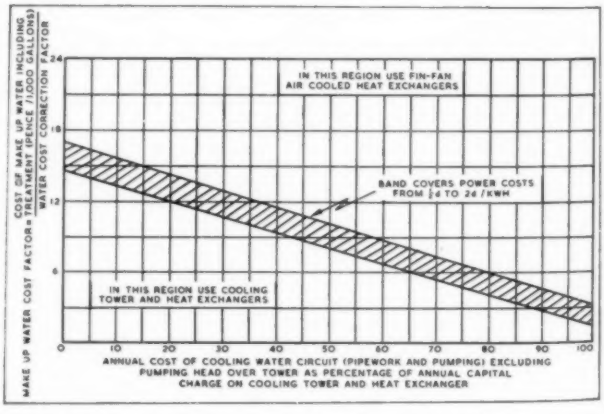

MAKE UP WATER COST FACTOR = COST OF MAKE UP WATER INCLUDING TREATMENT (PENCE /1000 GALLONS) / WATER COST CORRECTION FACTOR
24
18
12
6
0
IN THIS REGION USE FIN-FAN AIR COOLED HEAT EXCHANGERS
BAND COVERS POWER COSTS FROM ½d TO 2d /KWH
IN THIS REGION USE COOLING TOWER AND HEAT EXCHANGERS
10
20
30
40
50
60
70
80
90
100
ANNUAL COST OF COOLING WATER CIRCUIT (PIPEWORK AND PUMPING) EXCLUDING PUMPING HEAD OVER TOWER AS PERCENTAGE OF ANNUAL CAPITAL CHARGE ON COOLING TOWER AND HEAT EXCHANGER

Fig. 1. Make-up water costs related to pipework and pumping costs.

* **Mr. Talbot** is a graduate of Imperial College, London University, with a degree in chemical engineering. He joined Head Wrightson Processes in 1950 and is now manager of the Special Products Department handling the detailed design, engineering and erection of cooling towers, air-cooled heat exchangers, etc.

† **Mr. Tow** is a graduate of University College, London University, with a degree in mechanical engineering and a post-graduate diploma in chemical engineering. He joined Head Wrightson Processes in 1953 as a chemical engineer in the Technical Sales Division of the Commercial Department, covering all aspects of the company's sales activities. In 1954 he was appointed head of the division and, in 1956, deputy commercial manager covering all the sales, estimating and purchasing functions of the company.

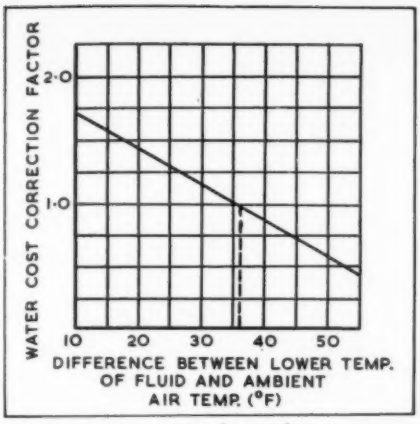


Fig. 2. Correction factor for make-up water costs.

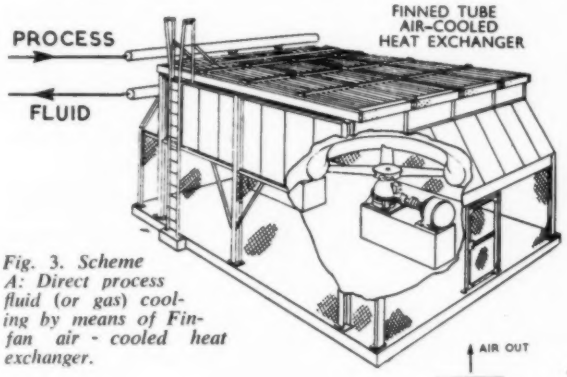


Fig. 3. Scheme A: Direct process fluid (or gas) cooling by means of Fin-fan air - cooled heat exchanger.

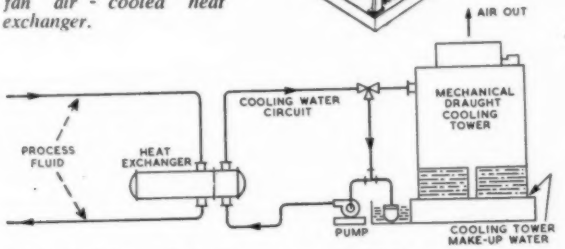


Fig. 4. Scheme B: Indirect process fluid (or gas) cooling by means of cooling tower and heat exchanger.

approach of the process fluid temperature to the ambient air temperature was varied. This fact led to the preparation of the second curve (Fig. 2), which gives a factor to correct the make-up water cost so that this latter figure may be correctly used in Fig. 1 under various approach temperatures. The make-up water cost factor is numerically equal to the cost of make-up water divided by the water cost correction factor which depends on the approach. It will be seen from Fig. 2 that when the approach is approximately 36°F, then the make-up water cost factor axis on Fig. 1 may be replaced by the cost of make-up water.

A recent article[2] gives the results of a study of the comparative cost of an air-cooled heat exchanger system and a cooling tower/heat-exchanger system. The duty considered in this study was to dissipate 80 mW of heat equivalent to 273 million Btu/hr. The demineralised process water was to be cooled from 142°F to 86°F with a wet-bulb temperature of 60°F and a dry-bulb temperature of 68°F. The most economic case for the water-cooling system was selected from calculations involving five cooling-tower ranges and four cooling-tower approach temperatures.

This case was obtained when the cooling-tower range was 50°F and the approach (wet-bulb temperature to cold-water temperature) 10°F. This means that in the cooling tower 8800 I.G.P.M. of water was to be cooled from 120°F to 70°F at a wet-bulb temperature of 60°F, and in the heat-exchanger process water was to be cooled from 142°F to 86°F by means of cooling water being heated from 70°F to 120°F. In the air-cooled heat exchanger process, water was cooled from 142°F to 86°F at an ambient air temperature of 68°F.

From Table 3 in Kaye's paper[2] the annual cost of the cooling-water circuit, pipeline plus pumping, is shown to be £13,020. The annual charge of the cooling tower and heat exchanger is shown to be £13,430. This results in a percentage factor of 97% for use on the ordinate of Fig. 1.

From the temperature range given and the heat load, a water make-up figure of approximately 460 I.G.P.M. can be calculated, and with the annual water costs given in the paper it will be seen that the cost of make-up water is of the order of 2s. per 1000 gallons. The difference between the process fluid temperature and the ambient air temperature is 86°F − 68°F = 18°F. From Fig. 2 this gives a water cost correction factor of 1.5. Therefore, the make-up water cost factor for reading on the abscissa of Fig. 1 should be 24 ÷ 1.5 = 16d. It will be seen, therefore, from Fig. 1 that ordinates of 16d. and 97% indicate that Fin-fans would be the most economic for the case selected. This in fact, bears out Kaye's conclusions from his detailed analysis of the specific problem.

In certain circumstances the cost of make-up water can be considerably less than the 2s. given above (where special treatment was required). This could well be, for instance, of the order of 1s. Allowing for the same water cost correction factor as calculated above, 1.5, our abscissa reading would then be 8d. Disregarding the actual cost of power/kWh, the curves show that, provided the annual cost of the cooling-water circuit expressed as a percentage of the annual capital charge on the cooling tower/heat-exchanger system is less than some 40%, cooling towers should be used. This means that the pipeline and pumping costs should be less than £5400 a year. Therefore, if this cheaper make-up water were available, the system would be economic if the cooling tower were sited much closer to the heat exchanger than was the case for the project previously considered.

Curves have Wide Application

It is believed that these curves have a wide application and may be used as a basis for a preliminary consideration of cooling schemes. They will, it is felt, also emphasise two important facts: first, that air-cooled heat exchangers should be used for direct-process cooling and not for cooling water which is then to be used in further heat exchangers; and secondly, that factors such as the pipework and make-up water costs are of the very greatest significance when considering the most economic cooling system. Unfortunately, it has been noticed that many engineers give little consideration to these factors.

It will be realised, of course, that these curves are only an approximate method of selecting the most economic cooling system. A final decision can only be taken after accurate calculations have been made giving due consideration to all factors. The cooling system must be considered in relation to the process plant in order that the best overall conditions can be selected; this work preferably being undertaken by a company offering all types of cooling system. Such a company will be able to prepare a detailed report and competent recommendations if it is given all the necessary information on the process for which the cooling system is required.

REFERENCES
[1] Report prepared by Head Wrightson Processes Ltd.
[2] Kaye D. *Brit. Chem. Eng.* **1**, 1956, 410, and **2**, 1957, 32.

AMERICAN LETTER

Biochemical Processing in America

THE commercial production of biochemicals is frequently handicapped by several factors which are comparatively unknown in other processes and these may originate in the raw material or occur during processing. Thus, the initial concentration of the desired compound may be extremely low—perhaps only one or two parts per million in the case of some vitamins and amino acids. In addition, the compound sought may be blanketed by undesirable complex organic materials which are extremely difficult to remove. Sometimes the only workable process may involve so many delicate operations that, unless extreme care and elaborate techniques are used at each stage, the yield may be reduced to commercial insignificance by molecular instability and high process losses.

In America, despite the availability of relatively cheap filter aids and the use of large, continuous filters, much work has been carried out on the processing of unfiltered broths, using specially designed centrifugal extractors, such as the Podbielniak, and continuous multi-stage centrifuges. Ion-exchange methods are also used for primary extraction (as well as in intermediate and final operations) and both the fixed-bed and the resin-in-pulp techniques are employed, after suitable screening and sterilisation. Precipitation from unfiltered broths on a plant scale is not in general practice, since subsequent recovery is usually hampered by the presence of organic slimes and cellular matter.

There is no doubt that ion exchange has proved to be one of the most useful unit operations in biochemical production, and American resin makers have developed this technique to a remarkable degree. For instance, by using different resins, a complex organic mixture can perhaps be fractionated and each component recovered separately. Another novel application is the use of resins to exchange one ion in an organic structure for another, e.g., halogens or alkali metals, so that different salts may be readily formed. It is not so simple, of course, for a chelated group. More recently, resins have been developed which enable a kind of dialysis to be carried out, since penetration and ion exchange occur according to the sizes of the respective ions and molecules. Thus, small molecules and ionic impurities migrate to the interior of the resin particle, while the larger, wanted molecules are confined to the surface and are removed by selective washing and exchange. Other applications of ion-exchange include demineralisation, deionisation and neutralisation, using the older fixed-bed methods as well as the newer fluidised-bed and resin-in-pulp techniques.

A promising field for further investigation is said to lie in the application of foam fractionation and froth flotation for biochemical recovery, especially as regards proteins and compounds of high surface activity. Other less-usual methods at present under study are said to include electrophoresis, thermal diffusion and chromatography.

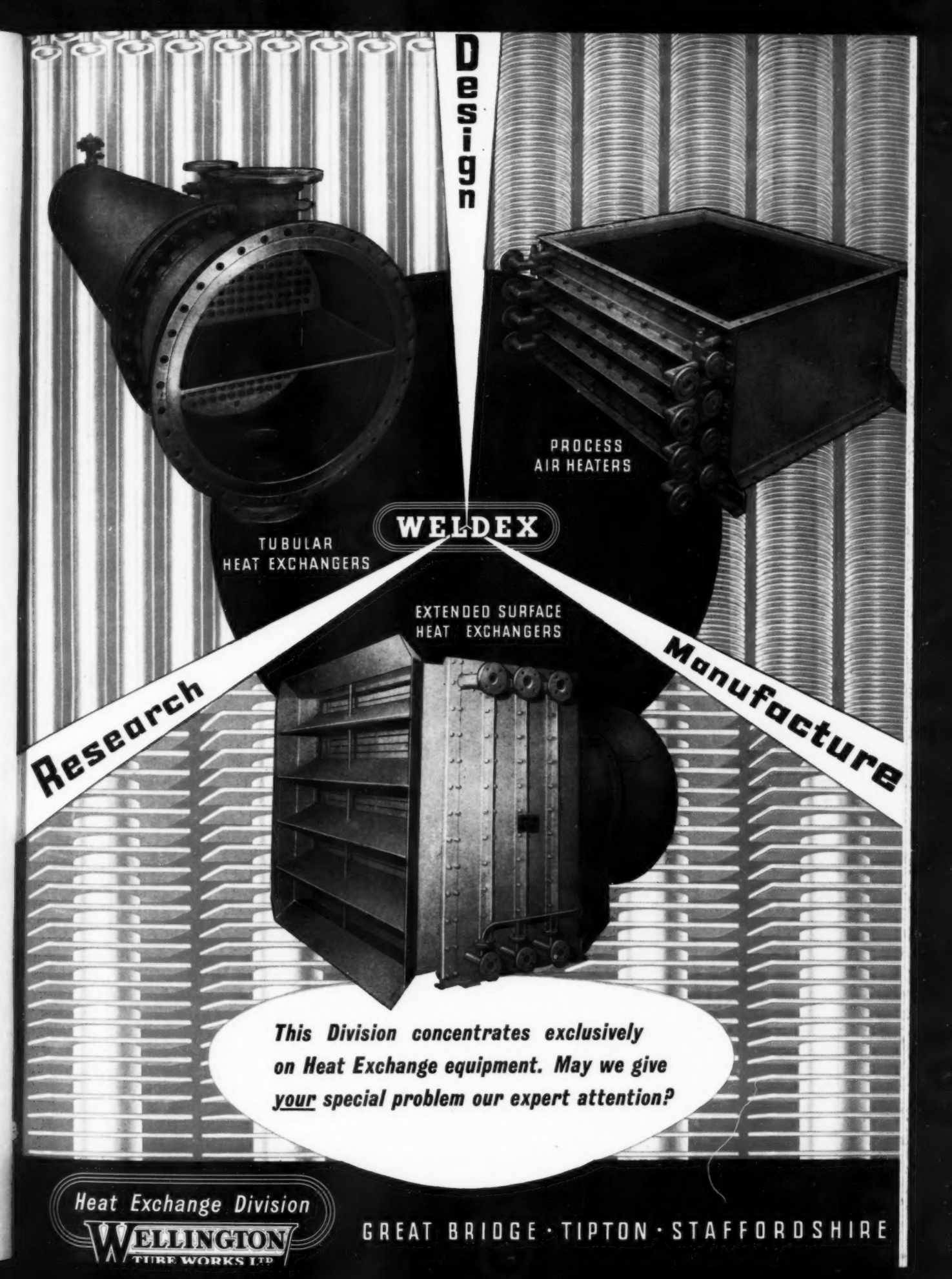
Regarding the more orthodox unit-operations used in biochemical preparation, some interesting evaporators have been developed, often on the lines of equipment used for food processing, both in America and Europe. Several types of spinning-film or wiped-film evaporators are available, with or without vapour recompression, and with a downflow feed, so as to eliminate boiling-point elevation due to liquid head. Heat-transfer rates are high, even with sensitive materials. Another item of equipment increasingly used for removing water from delicate materials is the freeze-drier, which separates the water in the form of sublimed ice, under appropriate conditions of temperature and vacuum. An extension of this device has led to the molecular still, in which compounds with different volatilities can be sublimed or volatilised at low temperatures under very high vacuum, using a short, free path for the mass transfer.

An indispensable operation in the production of numerous biochemicals is solvent extraction by mechanical means and, as previously mentioned, the Podbielniak machine has been especially valuable. In chloromycetin manufacture, for example, the use of this extractor on unfiltered broth was said to have reduced process costs by over 31%, as well as giving a 10% increase in yield. One model is capable of handling 25,000 gallons of feed an hour, with as little as 0.02 difference in the specific gravities of the two liquids. The intimate contacting occurring in such a machine enables the fullest advantage to be taken of favourable distribution coefficients when they exist, and so makes possible a large volume reduction, which may amount to 100:1 or even more in some cases. Other equipment used for solvent extraction on a commercial scale, especially for the intermediate steps in a process, includes multi-stage deep bowl centrifuges, pressure centrifuges, liquid cyclones and packed columns of special design.

Materials of Construction

No short review of modern biochemical processing would be complete without a reference to materials of construction and ambient conditions, for the chemical engineer and his allies, the metallurgist, the glass technologist and the plastics specialist, have met virtually every difficult challenge. Where absolute purity and sterility are paramount, the use of glass may be essential and it is now possible to obtain reliable glass-lined mechanical equipment such as pumps and agitators, in addition to static vessels and piping of enamelled or glass-coated construction. Some process reactions are so sensitive that even the accelerators and other compounding materials present in rubber and plastic tubing can cause adverse effects; nevertheless, special elastomers have been developed to provide the necessary inertness, without loss of flexibility or corrosion resistance. Stainless steels and the newer metals also find wide application, seemingly without limit to the skill of the fabricator. Often, the resemblance to laboratory equipment is strong, and in America one can see conventional large-sized laboratory apparatus adapted for use in the late production stages of some biochemicals.

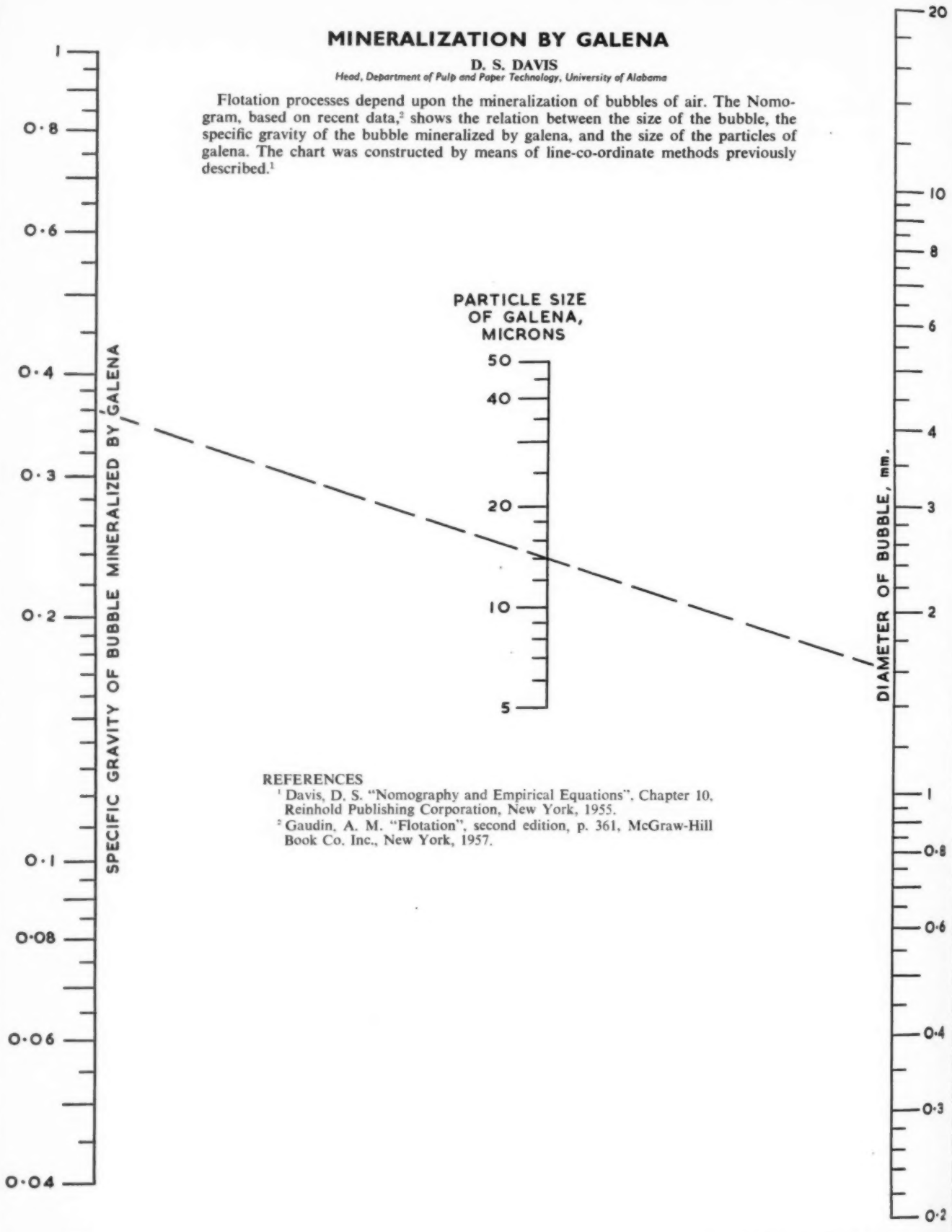
Since many complex organic compounds are sensitive to bacterial action as well as chemical impurities, and may also be intended for direct medical use, sterilisation of raw water, plant air, equipment and operators is frequently essential. Irradiation with ultra-violet light, filtration of water and plant air, and similar safeguards are practised on a wide scale, especially in the final production stages. Some companies have gone all out to provide lavish aseptic conditions in their filling and packing departments; on both sides of the Atlantic, the hospital-like aura thus created has been found beneficial both to product purity and to sales publicity.


Design
PROCESS
AIR HEATERS
WELDEX
TUBULAR
HEAT EXCHANGERS
EXTENDED SURFACE
HEAT EXCHANGERS
Research
Manufacture
This Division concentrates exclusively on Heat Exchange equipment. May we give your special problem our expert attention?
Heat Exchange Division
WELLINGTON
TUBE WORKS LTD
GREAT BRIDGE · TIPTON · STAFFORDSHIRE

MINERALIZATION BY GALENA

D. S. DAVIS
Head, Department of Pulp and Paper Technology, University of Alabama

Flotation processes depend upon the mineralization of bubbles of air. The Nomogram, based on recent data,[2] shows the relation between the size of the bubble, the specific gravity of the bubble mineralized by galena, and the size of the particles of galena. The chart was constructed by means of line-co-ordinate methods previously described.[1]



REFERENCES
[1] Davis, D. S. "Nomography and Empirical Equations", Chapter 10, Reinhold Publishing Corporation, New York, 1955.
[2] Gaudin, A. M. "Flotation", second edition, p. 361, McGraw-Hill Book Co. Inc., New York, 1957.

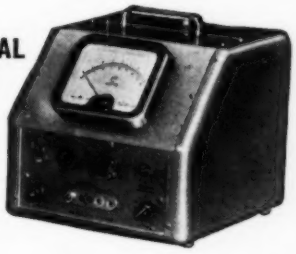
Signor Alessandro Volta

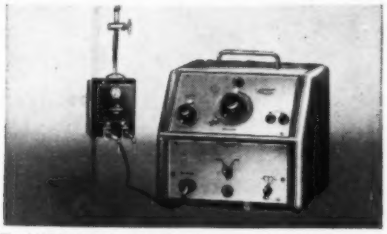
Gave himself quite a jolt,
But, taking his shocks
with a smile,
He called his invention
a VOLTAIC PILE!

There's no doubt the Signor must have put a good deal of thought into his work on electricity—we sympathise with him, because we're in the habit of putting a lot of thought into Pye Scientific Instruments! They're craftsman-built, with a real feeling for the needs of the man on the bench, whether in laboratory or industry. It's a pity the Signor isn't here today to see the results of part of his discoveries. We don't know if he'd approve of the telly, but we're quite sure he'd use Pye Scientific Instruments!

UNIVERSAL pH METER
Cat. No. 11067

This accurate and dependable instrument with its versatile electrode assemblies is first choice in most of the leading research and control laboratories.





PYE AUTOMATIC TITRATOR and DELIVERY UNIT
Cat. No. 11600. Cat No. 11610.

PYE AUTOMATIC TITRATOR, Cat. No. 11600 **and DELIVERY UNIT,** Cat. No. 11610.

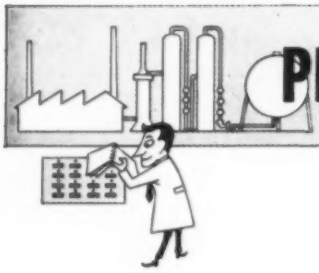
The Pye Automatic Titrator is used in industrial research laboratories for a great variety of titration and control problems. Combined with the Universal pH Meter, it can be relied upon to carry out Acid-Base and Redox titrations time after time with excellent reproduceability.

Please address complaints about this advertisement or requests for information on Pye Chemical or Physical Instrumentation to:

SCIENTIFIC PYE INSTRUMENTS

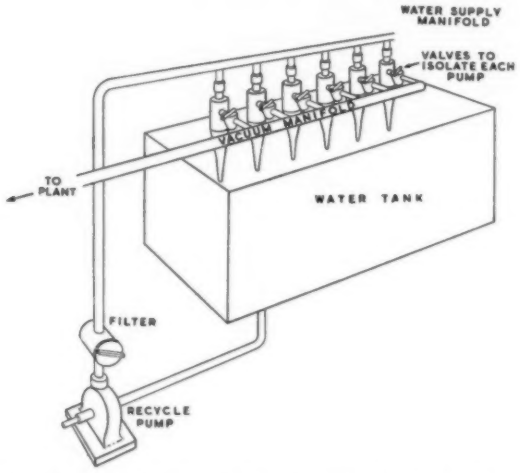
W. G. PYE & CO., LTD.

GRANTA WORKS, NEWMARKET ROAD, CAMBRIDGE
Telephone: Cambridge 54411 Telegrams: Pye-Cambridge



PROCESS ENGINEER'S NOTEBOOK

Novel Pumping Unit



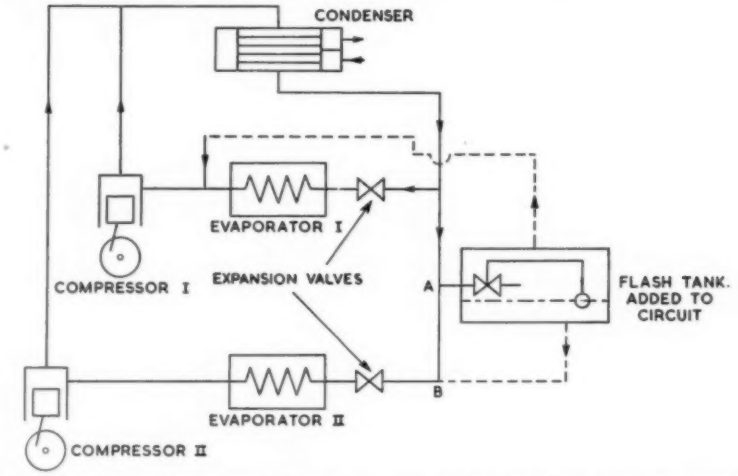
A CLIMBING FILM Q.V.F. glass evaporator erected in the Ramsay Laboratory of Chemical Engineering, University College, London, was designed to boil off 10 gal. an hour of 5% aqueous pyridine under a vacuum of 29-28 in. The only available pump was a rotary oil vacuum of the non-scavenging type, and it was obvious that a dry-ice trap would be needed to free the pumped stream from condensible gases to prevent oil dilution and contamination. After consideration, it was decided to try a pumping unit consisting of laboratory water-jet pumps working in parallel.

The final design (see accompanying figure) consisted of six plastic and steel water-jet pumps (Edwards High Vacuum Co. Ltd.) fed from a common manifold and discharging into a large surplus-water tank. All vacuum arms drained a common manifold leading to the condenser side of the evaporator. According to the specification of the pumps, a total of 800 gal. an hour of water would be required at a head of 20 psi, or greater. This volume was too considerable to pass to waste, so a recycle system was fitted employing a small, inexpensive centrifugal pump delivering 800 gal. an hour at 22 psi.

Experience showed that valves were necessary so that each pump could be tested and isolated if faulty. A good, fine-mesh filter was also found to be essential, because clogging of the fine nozzles is rapid with only a trace of dirt or dust in the water. Tests have shown that a vacuum near the maximum for a water-jet pump is achieved —20-30 mm of Hg—as is a satisfactory pumping speed. Ten minutes are needed to evacuate a volume of 40-50 l. to 28.5 in. So with a capital outlay of less than £50, a pumping unit consuming only 700 watts power and doing an admirable job was obtained.

M. C. REECE.

Reducing Refrigeration Plant Power Consumption

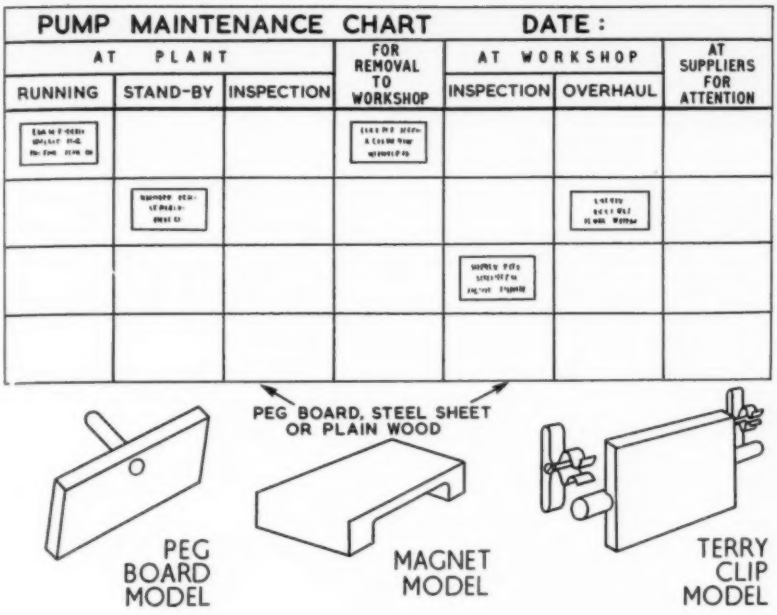


POWER CONSUMPTION in a refrigerating system employing two compressors and two evaporators operating at two different temperatures can be reduced by installing a flash tank. This measure allows the refrigerant to expand in two stages to the pressure at the lower temperature evaporator, so that the flash vapour from the partial expansion is compressed to the condenser without unnecessary expansion to the lower pressure in the system.

The arrangement shown in the diagram, which allows the flash tank to be by-passed if necessary, will give an increase in refrigeration capacity at the lower temperature level. There will, however, be some loss in capacity at the higher temperature level.

Depending upon the dimensions of the expansion valve in the low-pressure circuit, a replacement may or may not be necessary. This is because less pressure drop will be available for the slightly greater quantity of refrigerant to be passed. The replacement can be fitted to by-pass the existing valve so that, if desired, the plant can be operated under its original conditions.

For an ammonia plant with equal evaporator loads and at evaporation temperatures of −18°C and 4°C respectively, a saving of 3 to 4% in power consumption can be made by means of the modification described above.



Maintenance Indicator Board

AT PLANTS where large numbers of ancillaries such as pumps are installed, systematic maintenance can be made easier by an indicating system by means of which the state of any particular piece of equipment can be seen at a glance. One method is to use a type of notice board with a number of vertical divisions. Each column can represent the actual location of a piece of equipment and whether, for example, it is in use, on stand-by, undergoing repair, or at the manufacturers for overhaul. This type of board contains a number of tabs upon which are written the details of the particular component, such as flow-sheet number, manufacturer and any other relevant information. Tabs corresponding to each pump or other ancillary are placed in their appropriate column.

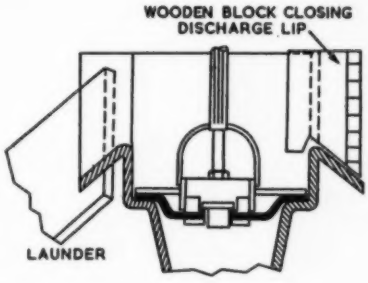
The indicator can be put into practice in a number of ways. The main board may consist of a sheet of thin steel and the tabs can be specially designed magnets which adhere quite readily to the sheet. This method is probably the most convenient to use, but other methods, such as peg-board or plain plywood using Terry clips (see diagram), can also be used.

Co-current Absorption Column Reduces Costs

IN SMALL air-distillation plants air compressed to about 10 atm. is scrubbed counter-currentwise with caustic soda to remove the major part of its CO_2 content. The packed absorption columns are normally provided with a large receptacle at their base to contain the scrubbing liquor, which is discharged when it becomes exhausted. Such an arrangement is too expensive to be used on large plants where the batchwise liquor method is replaced by a continuous feed of absorbent to the absorption column. There are advantages also in passing the air and caustic liquor co-currently down the absorber. This arrangement overcomes entrainment difficulties and permits much higher superficial air velocities and therefore smaller column diameters than are possible with counter-current operation. Factors such as the partial pressure driving force and mass-transfer coefficient are not adversely affected by the change from counter-current to co-current operation. The net result is a compact absorption unit, smaller in proportion to its throughput than the counter-current absorbers used in the smaller air liquefaction and distillation plants. (Prepared from the paper "The Effect of Scale on Air-separation Plant Design", by P. M. Shuftan and J. Forrest, and read at the symposium on the Scaling-up of Chemical Plant and Processes; organised by the Institution of Chemical Engineers, May 1957.)

Double-lip Diaphragm Pump Feeds to Thickener and Filter

A DOUBLE LIP diaphragm pump can be made to serve a double purpose by fitting obstructions to either discharge lip so as to divert the slurry to one or other parts of a plant. At one particular ore-milling plant detachable wooden blocks are employed for this purpose. They are made sufficiently high to divert the entire output of the pump across the unblocked lip. The pump can therefore feed either pulp concentrate to a thickener or pulp to a rotary filler. If the filter is shut down for any purpose, the thickener discharge can be recycled. The diagram (above) shows a cross-sectional view of the pump with a wooden block in position. (This item is by courtesy of The Denver Equipment Co. of Denver, Colorado.)



Contributions invited

THE EDITOR invites readers to submit, for possible publication in "Process Engineer's Notebook", notes on practical devices that have been elaborated on the job for improving the operation or increasing the safety of processes, or that have been extemporised in special circumstances. The contributions preferably should be of about 250-500 words, and be illustrated with a line diagram or sketch, or a photograph. A minimum of three guineas will be paid for each contribution used. They will be published anonymously or under the contributor's name, according to his wishes.

World of Chemicals

Expansion in Scandinavia

A process for removing the iron content of titanium ore mined in the Jossingford district of Norway has been elaborated by Titem A/S. At present the ore exported from this district contains 44% titanium oxide and 35% of iron, and, during 1957 the export of ore is expected to be equivalent to 12% of the world's total production of titanium oxide.

The administrators of the North Norway Development Fund and the Narvik municipality are discussing the possible construction of a sponge-iron plant at Narvik which would have an annual production of 37,000 tons of the iron and 200,000 tons of coke. Negotiations are also in progress to interest Swedish industry in the problem.

For the purpose of working sulphur pyrites deposits at Gjersvik, Norway, which are estimated at 1.4 million tons, a proposal has been made to the Norwegian Government to reorganise the Groug Co.

Du Pont's New Canadian Plants

The $7-million commercial explosives plant erected at North Bay, Ontario, by Du Pont of Canada has been officially opened. It occupies 50 acres of a 4000-acre tract in West Ferris, has been built by Fraser-Brace Engineering, Ontario, and provides initial employment for 110 men. It is said to incorporate the latest technological advances in the industry. The plant is the second which Du Pont is bringing into production this summer, the other being an $8-million installation for the manufacture of Orlon acrylic fibre at Maitland, Ontario.

Natural Gas from Pembina

A proposal to use compression and refrigeration techniques for gathering natural gas from the Pembina oilfield, Canada, has been announced by Goliad, a Canadian subsidiary of H. W. Bass. The gas would then be piped to a central plant for processing the liquid components. Implementation of the plans would involve a capital expenditure of about $17 million, $2 million of which would be allocated to the processing plant to be built in Drayton Valley, West Edmonton. The completion date would be early 1959.

New Element

Element 102, the discovery of which was announced recently, was first observed and isolated on March 23, 1957, at the Nobel Institute, Stockholm, during work being undertaken by an international research team composed of scientists from Sweden, Great Britain and the United States. The element, which is the first to be made since 1955, was produced by bombarding curium (element 96) with carbon ions accelerated in the Institute's cyclotron.

Pakistan Oil Refinery

The Pakistan Government has asked Burmah Oil, Shell Petroleum, Caltex and Standard Vacuum to submit proposals for a refinery for the country. Initial estimates put the cost of the proposed refinery at about Rs.260 million, but an investment of as much as Rs.450 million spread over five years may be needed to make the refinery a fully economic unit.

Ecuador Sulphur

The possibility of re-exploiting the Tixen sulphur mines in Ecuador is being examined by Brazilian experts. Brazil, which has no sulphur, would be interested in purchasing this commodity eventually from Ecuador. A Yugoslav firm has offered to supply all the matches that Ecuador needs in return for 6000 tons of sulphur annually.

Development in Titanium Manufacture

As a result of research conducted at the Armour Research Foundation, it has been announced in America that titanium tetrachloride, needed for the manufacture of titanium, can now be produced at much lower temperatures than previously. The purity is higher and the cost less.

Chemicals in India

Travancore Chemicals have commissioned a new plant for the production of fungicides at Alwaye, Kerala. At first about 3000 tons annually of copper sulphate will be manufactured (sufficient to meet India's needs of the compound for fungicidal purposes). Later the plant will produce copper oxychloride, cuprous oxide and other fungicides.

Portuguese Government Allocations

The Portuguese Government have allotted 135 million escuados (£1.68 million) for the manufacture of nitro-ammoniacal fertilisers. Two new factories are to be working by 1959 to produce 80,000 tons of nitrogenous fertilisers annually, as well as supplying gas for domestic use in Lisbon.

Brazil Refinery

Foster Wheeler of the United States have been awarded the contract for engineering services for the construction of a new oil refinery in Petrobrás, Rio de Janeiro. The refinery's capacity will be 90,000 barrels a day. Some of the equipment may be purchased in Britain.

Turkish Cement Industry

Turkey's eighth cement works—at Adana—was opened by the country's Prime Minister recently. It has a yearly production of 150,000 tons. Seven other cement works, with annual productions of 85,000 tons each, are at present under construction.

Japanese Petrochemicals

The Maruzen plant in Wakayama Prefecture is reported to be the first plant in Japan to produce petrochemicals. In October, Mitsubishi Petrochemicals is expected to start making aromatics, and Sumitomo to start producing ethylene products.

Supply of U.S. Uranium

The quantity of uranium-235 which the U.S. Government is to make available over "a period of years" for peaceful purposes and for division equally between home and foreign users has been increased from 40,000 kilos to 100,000 kilos. It will be sold or leased.

Burmese Caustic Soda Plant

A plant to manufacture caustic soda, chlorine, hydrochloric acid and bleaching powder is to be erected in Burma by a newly-formed private company, Electro-Chemical Industries & Trading Co., which has an authorised capital of £187,500.

India's Need of Technologists

About 2500 specialists trained in "chemical engineering and technology" will be required in India during the next five years, according to an estimate published recently by the Indian Ministry of Labour and Employment.

Yugoslav Fertiliser Production

The Yugoslav Government has adopted a plan for the increased production of fertilisers. Three new factories are to be built, and during the next five years it is hoped to produce 1.7 million tons of fertilisers in the country.

Titanium Plant for Mexico

Du Pont have announced plans to build a £1 million titanium dioxide plant in Mexico. A sulphuric acid plant having a daily capacity of 150 tons has been ordered by Guanos y Fertilisantes S.A. from the Panamercan Consulting Co. Inc.

Development of Lignite

Powell Duffryn Technical Services have been appointed technical advisers to the mining section of Neyveli Lignite Project, India. The organisation's plans include the production of fertilisers by the end of 1960.

Greek Oil Refinery

The new Greek refinery at Aspropyrgos is expected to be ready for commissioning before Christmas and the Greek Government has invited tenders for its operation.

Navarre Potash Development

The Spanish National Institute of Industry is to erect a factory for the exploitation of potassium salts in Navarre, with a production of 200,000 tons of anhydrous potassium oxide annually.

Chemicals for Industry

Catalysts

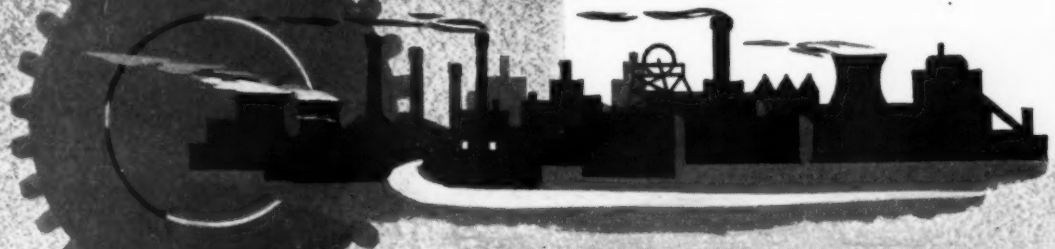
Aluminium sulphate

Alum

Organic compounds of titanium

Activated and other special aluminas

Details of the properties and applications of these and other Spence chemicals will be supplied on request.



SPENCE

Peter Spence & Sons Ltd · Widnes · Lancs
also at London & Bristol

5102

Book Reviews

Liquid Metals Technology (Part I)—Chemical Engineering Progress Symposium Series No. 20, Volume 53

American Institute of Chemical Engineers, New York; 1957, 84 pp.

THIS volume is a recent addition to the series of symposium publications produced at intervals by the American Institute of Chemical Engineers and it comprises a group of excellent papers on liquid-metal technology sponsored by the Institute over the last year and a half at the Cleveland Nuclear Science and Engineering Congress and elsewhere. It is of particular interest to those concerned with advanced reactor experiments in the field of high specific power rating and small core size.

Several advanced heterogeneous reactors employ liquid metals as a coolant, the most important of which are the fast, unmoderated reactors using uranium or plutonium fuel elements cooled by liquid sodium or its eutectic with potassium, and the sodium-graphite thermal reactors employing slightly enriched fuel cooled by sodium in a graphite lattice. In addition, considerable attention is now being given to the development of a homogeneous reactor of the liquid-metal type. These liquid-metal-fuelled reactors are of particular interest, since they seek to utilise circulating solutions of enriched uranium in bismuth in the same way in which heavy-water solutions of uranyl sulphate have been proposed for the homogeneous aqueous reactor.

Such reactor concepts have led to extensive studies in the fields of liquid-metal corrosion, mass and heat transfer, and the present papers include a considerable amount of new information. The compilers of the series have made a good selection from the material available to them and have included four papers on the effects of impurities and mass transfer, two papers on heat transfer and a number of papers on diverse subjects covering chemical processing, materials of construction and the manufacture of alkali metals.

The paper by Humphreys on the "Sampling and Analysis of Impurities in Liquid Sodium Systems" describes possible solutions to a perennial problem in experimental work of this type. It is well known that the concentrations of small impurities, particularly oxygen, is a significant feature in the metallurgical problems associated with sodium coolant at high temperature and one of the difficulties in experimental work is to obtain a reliable method of analysis. The paper critically examines existing measurement techniques and suggests a method based on vacuum distillation using a special sampler to isolate non-volatile impurities. The paper is limited in scope and somewhat disappointing in that few results are given to indicate the accuracy and reliability of the method. A companion paper to this is the "Control of Oxygen in Sodium Heat Transfer Systems" by Gray, Neal and Voorhees. Here the problems associated with holding the oxygen content to a low level by the use of cold trapping is discussed, and the authors describe the use of an oxide plugging indicator claiming reproducible accuracy for oxide determinations as low as 3 ppm.

A paper on the problems of "Material Transport in Sodium Systems", by F. Haag, examines the effect of oxygen concentration and temperature on mass migration in stainless-steel circuitry. The results quoted have been obtained by tracer techniques, and the paper discusses the effect of inhibitors on mass transfer and confirms the role of barium as the inhibitor most likely to reduce the oxygen to desirable limits.

Brush and Keonig, of the Knolls Atomic Power Laboratory, discuss the use of low-cost materials for sodium heat-transfer systems in a paper which is important if only because the authors recognise that the use of sodium in reactor circuits is very much determined by the high capital cost of the stainless-steel components involved. This is particularly true at the present time when the designer of liquid-metal heat exchangers tends to sacrifice heat-transfer efficiency in order to guarantee that no direct contact shall occur between the liquid metal and the water/steam circuits if either should fail. The paper discusses alternative materials of construction, and suggests that ferritic alloy steels are adequate for use up to 538°C, a view which must be accepted cautiously until further work has been done to confirm it.

A satisfactory solution to the many problems involved in the chemical processing of active high-temperature metal is essential to the success of any liquid-metal homogeneous system. R. J. Teitel analyses some of these problems in detail and describes a possible precipitation technique based on work carried out at Brookhaven. This paper can be usefully compared with the work on fused salt techniques carried out in the same laboratory and discussed in an earlier paper by Bareis, Wiswall and Winsche (Chemical Engineering Progress Symposium No. 12, Vol. 50).

An abstract of other papers in the field of liquid-metal technology is included in a useful appendix. B.E.E.

Heterocyclic Compounds, Volume 6

Edited by Robert C. Elderfield
Chapman & Hall Ltd., London, 1957, 753 pp., 200s.

THIS important series which started in 1950 under the editorship of Prof. Elderfield is not an encyclopædia of heterocyclic compounds, but is concerned with the principles of their chemistry. Volume 6 deals with the six-membered heterocycles, containing the heteroatoms N, O or S, and their benzoderivatives. The 14 chapters have been contributed by various authors, mainly American, with one British contribution from Cambridge University. They deal with monocyclic dioxanes, benzodioxanes, sulphur analogues of dioxanes (but not with 1,2-dioxanes and 1,2-dithianes, since their chemistry resembles that of the peroxides and disulphides), pyridazines (it should be interesting to ascertain whether aliphatic azines such as acetaldazine, form pyridazine systems, on causing them to react with dienes), cinnolines, phthalazines, pyrimidines, quinazolines, pyrazines and piperazines, quinoxalines, oxazines and thiazines, phenazines, phenoxazines and phenothiazines.

Some of the classes of compounds discussed in this volume show interesting properties as drugs (thus, some phthalazines show high antitubercular activity, some pyrimidines constitute important hypnotics, certain quinazolines possess antimalarial activity, and chlorpromazine, a derivative of phenothiazine, has possibilities in psychiatric treatment), as insecticides (oxazines and thiazines) and dyes. Certain morpholines are said to be useful as antioxidants for rubber, as photographic developers, and as metal corrosion inhibitors for acid descaling solutions; also various morpholinium alkyl sulphates were found interesting as "invert" soaps.

The series "Heterocyclic Compounds" is an essential tool for the research worker engaged in the heterocyclic field of organic chemistry. The price of the present volume, which contains cross-references to earlier volumes and, in general, covers the major English and German journals up to 1955 (inclusive), is, however, high for the British market. M.P.

Man and Automation

by L. Landon Goodman
Penguin Books, Middlesex, 1957, 286 pp., 3s. 6d.

THE author of this essay, an introduction to automation, treats the subject widely and loftily. One consequence, however, is that many facets of the "adventurous world", which he claims automation will usher in, have to be compressed stringently within the book's small compass. Mr. Goodman divides the text into two sections, dealing respectively with the technical aspects and the social and economic effects of automation. His real message, which relates to the urgency of dispersing ignorance and admitting informed discussion on automation, lies chiefly in the second half. His style is descriptive and the book is suitable both to laymen and, within its limitations, to managers who have a special responsibility for installing automation. Discussing the chemical industry, the author asserts that already this industry has passed the point where further labour can be saved by instrumentation, as staffing is now based on that needed for coping with emergencies. In the oil industry, however, although much use is made of automatic operation, there is still no overall automatic control. Many of the necessary instruments to measure product quality continuously do not exist or are not fully reliable, and developments will have a long way to go before a self-regulating chain of process is achieved. The author is repetitive in his ideas on the inevitableness of automation and the benefits, social and economic, which will be derived from it. G.D.

Ready in the Autumn

A Treatise on the Internal Mechanics of Ball, Tube and Rod Mills

by H. E. ROSE and R. M. E. SULLIVAN

Ex. Cr. 8vo. Illustrated about 21s.

Chemical Engineering Operations

An introduction to the Study of Chemical Plant

by F. RUMFORD, Ph.D., B.Sc., M.I.Chem.E.

Demy 8vo. 376 pages Illustrated 32s. 6d.

Chemical Engineering Materials

by F. RUMFORD, Ph.D., B.Sc., M.I.Chem.E.

Demy 8vo. 350 pages 32s. 6d.

Electrostatic Precipitation in Theory and Practice

by H. E. ROSE and A. J. WOOD

Cr. 8vo. 168 pages 17s. 6d.

The Petroleum Acids and Bases

by H. L. LOCHTE and E. R. LITTMAN

Demy 8vo. 360 pages 50s.

Refrigeration and Air Conditioning

by R. C. JORDON and J. B. PRIESTER

Revised Edition

Med. 8vo. illustrated 65s.

Human Relations For Management

The Newer Perspective

Edited by E. C. BURSK

8vo. 372 pages 27s. 6d.

Brings together the best of current thinking, selected by the editor from the pages of the *Harvard Business Review*.

CONSTABLE & CO. LTD.

10 ORANGE STREET, LONDON, W.C.2

CHAPMAN & HALL

★ *New Books* ★

THE CHEMICAL FORMULARY

Volume X

Editor-in-Chief

H. Bennett

(Technical Director, Glyco Products Co., Inc.)

392 pages *63s. net.*

This new volume in the well-known Chemical Formulary series is a collection of new, up-to-date formulæ. The only repetitious material is the introduction (Chapter I) which is used in every volume for the benefit of those who may have purchased only one volume. The list of chemicals and their suppliers has been enlarged with new trade-mark chemicals so that buying the required ingredients will present no problem.

GAS CHROMATOGRAPHY

by

A. I. M. Keulemans

(Research Chemist, Koninklijke/Shell Laboratorium Amsterdam, Holland)

Edited by

C. G. Verver

217 pages *Illustrated* *60s. net*

A concise, authentic and up-to-date summary of the field, written by chemists who have for many years been among the most active investigators of all varieties of chromatography. The variety of applications described, and the additional applications to be thought of, make this work invaluable to all gas or vapour analysts and of interest to all those connected with the manufacture of chemicals, pharmaceuticals, plastics, etc.

THE CHEMISTRY OF ORGANOMETALLIC COMPOUNDS

by

E. G. Rochow; D. T. Hurd; R. N. Lewis

(Respectively at: Department of Chemistry, Harvard University; General Electric Company; Olin Mathieson Chemical Corporation.)

344 pages *Illustrated* *68s. net.*

This work offers what is probably the first review and survey of the subject up to 1956. It contains information on all phases of organometallic compounds: structure and physical properties, preparation, chemical reactions and applications. The subject matter is organised on the basis of the general properties of the carbon-metal bond; electronegativity and bond polarity are used freely as indicative of the type of organometallic compound to be expected in a given instance.

37 ESSEX STREET, LONDON, W.C.2

PLANT EQUIPMENT NEWS

A Flexible Furnace

Electrothermal are augmenting their existing range of flexible heating equipment for industry and science by the addition of the Flexible Furnace. For all applications where large areas have to be subjected to high temperatures, the Flexible Furnace represents, the makers say, an entirely new technique. It is a heavy-duty heater built up from a network of resistance wires insulated by specially constructed interlocking high-temperature-resistant ceramic blocks, and it is designed to have a surface loading of up to 50 w./sq. in. (7.75 w./cm.²). Controlled temperatures of up to 1000°C are obtainable. The basic unit, the high-temperature-resistant ceramic block, approximately $\frac{5}{16}$ in. thick by $\frac{3}{4}$ in. × $\frac{5}{8}$ in. (8 mm. × 19 mm. × 16 mm.), functions independently of, but is securely attached to, its adjacent members. This construction allows a high degree of flexibility and the

heaters can be applied to parts having a diameter as small as $\frac{1}{2}$ in. Curvatures with a minimum radius of 24 in. can be accommodated in a direction at right angles to the direction of maximum flexibility. Rectangular heaters can be supplied in sizes up to 48 in. × 48 in., and, for all applications where the working surface area is greater, two or more heaters can be linked together. Heaters can also be supplied in a variety of other shapes as required. **Electrothermal Engineering Ltd., 270 Neville Road, London, E.7.**

BCE 1810 for further information

Automatic Air Filter

The Autoroll, a new kind of filter suitable for large-capacity air filtration, has been designed by Vokes, and the makers claim that it combines all the advantages of dry- and viscous-type filters. It is automatic and the effective area of the filtering medium, which is fibrous, is disposed between two spools, the upper containing the clean medium, and the lower the fouled medium. Movement of the medium is effected by a geared motor drive operating intermittently on a time- or pressure-controlled cycle. The unit can accommodate a variety of media without modification to the main structure. The filtering medium is a fibrous mat comprising secondary acetate fibres carded to an even density and fused at their intersections to give sufficient strength and elasticity to resist the tension met in service and to maintain elasticity so that it will return to its nominal thickness after compression on the spool. The Autoroll equipment embodies standard warning mechanisms. **Vokes Ltd., Henley Park, Guildford.**

BCE 1811 for further information

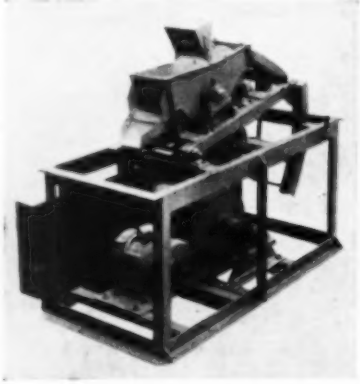
Knitted Demisters

Knitted Mesh are making available demisters made from wire knitted to produce a mesh of linked loops. Knit Mesh, as the product is known, is made in many combinations of interstice size, wire diameter and materials. In addition, the wire can be either round or flattened and the mesh crimped. Because of its structure, Knit Mesh, it is said, has both a large surface area and a large free space. A removal efficiency of 99-100% at usual operating conditions is claimed for the demister, and the pressure drop is normally less than 1 in. w.g. Maintenance costs are said to be negligible. **Knitmesh Manufacturing Co., 36 Victoria Street, London, S.W.1.**

BCE 1812 for further information

Vibrair Jigs

Designed for the dry separation and recovery of material in the size ranges between $\frac{1}{2}$-in. cube and 10-mesh B.S.S., the Vibrair jig operates on material in the dry state and is particularly effective when scalping low-grade material to produce a clean tailing. In this connection it has found many applications, including the elimination of barren waste in grinding circuits, the preparation of high-grade non-metallic minerals where undesirable impurities were required to be removed, and in the recovery of valuable material from industrial wastes. The unit is manufactured in three sizes—the laboratory model, No. 1 and No. 2 size. Capacities for these units are from 100-200 lb./hr, 500-800 lb./hr and 1000-1500 lb./hr respectively, the throughput varying with the type of feed and type of concentration required. The Vibrair jig is one of a range

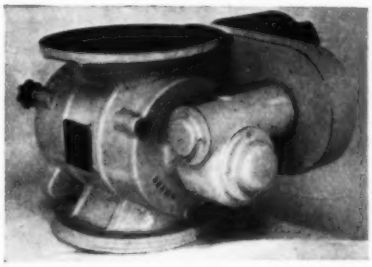


of units designed for the treatment of material in the dry state. Other units consist of dry tables, for treatment of finer material, and aero jigs for the treatment of coarser material and for the production of preliminary concentrates from unsized feed. **Knapp & Bates Ltd., Africa House, Kingsway, London, W.C.2.**

BCE 1813 for further information

Rotary Airlocks

Derion rotary airlocks, which have been recently developed by Bush & Wilton, are manufactured in 5-, 8-, 10-, 12-in.



and larger sizes. The makers state that they can be used for either discharging or feeding any pneumatic conveying dust systems, dust collectors, cyclones, pulverisers, etc. The sealing blades are adjustable and replaceable and all moving parts are mounted on grease-packed, sealed-for-life ball races which are external to the dust chamber. The unit is precision made, 2% nickel-cast-iron castings are used for the main components and for most applications flexible blades are fitted to give a wiping action around the inside of the housing to prevent the build-up of gummy materials. Special units for handling powder or granular materials having corrosive or abrasive properties can be supplied, or for working temperatures up to 300°C. **Bush & Wilton, The Old Foundry, Bitton, near Bristol.**

BCE 1814 for further information

New Welding Electrode

Murex Research Laboratories have developed a new electrode known as the Fortrex 35A type. This electrode, say Murex, gives all the required properties in the welded joint in extra-thick plates and the weld metal has particularly good impact properties at sub-zezro temperatures. The electrode also has all the advantages of the standard Fortrex 35 type. It is an all position electrode; it is simple to use, slag removal is easy and the radiographic quality of the weld metal is sound. **Murex Welding Processes Ltd., Waltham Cross, Herts.**

BCE 1815 for further information

Comminuting Mill

The new Apex comminuting mill, No. 180, is a robust and precision-built machine in stainless steel for size reduc-

We got involved in a powder sort-out...

. . . so we built the Super Classifier to do the job

WE KNEW THERE were quite a lot of customers who would like to have a high efficiency machine to divide powdered materials into fractions according to particle size. So we went into the problem at some length—nearly ten years in fact. And out came the Sharples Super Classifier, which is an ideal air vortex type classifier. We knew that the chemical, minerals and metal industries who wanted this machine would judge it on three main factors—topsize point, yield and capacity. The performance figures had to be good. And so they are !

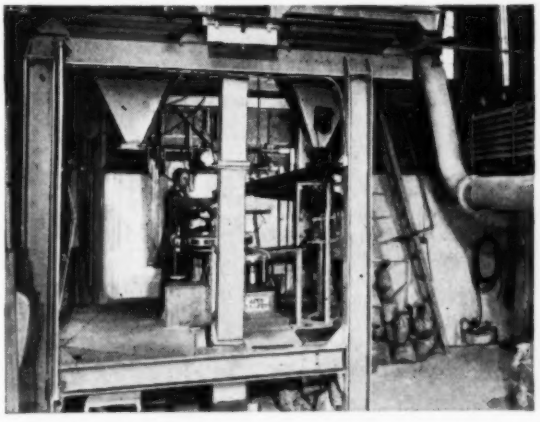
The cutpoint—the particle size about which the powder is divided—is exceedingly precise in the Super Classifier. For instance fine fractions with a top size of 15-20 microns will contain less than ·01%–·04% 325 mesh screen residue.

Product recovery or yield varies from 80% to well over 90% depending on product requirement.

Because topsize point and efficiency of the Super Classifier are not affected by the feed rate, you get high production capacities combined with high quality product.

The Super Classifier operates continuously without adjustment and an absolute minimum of operator's attention is required. To change from one cutpoint to another is a simple matter requiring only the changing of two vane rings and a drive pulley—which takes less than an hour.

Sharples are always ready to advise on any processing problem whether it's about a complete process or a single machine. Write to address below or 'phone Camberley 2601 and talk to Graham Jackson about your problem.



SHARPLES *Sharples Super Classifier Test House. Write for Bulletin No. 1280M for further information.*

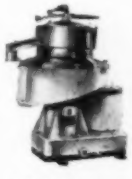
SHARPLES

Complete plants developed by Sharples include :

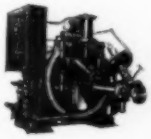
SHARPLES LOW LOSS VEGETABLE OIL REFINING PROCESS · SHARPLES STANDARD CAUSTIC VEGETABLE OIL REFINING PROCESS · SHARPLES CONTINUOUS SOAP PROCESS · SHARPLES WOOL GREASE RECOVERY PROCESS · SHARPLES LOW TEMPERATURE FAT RENDERING PROCESS · SHARPLES NAPHTHALENE PROCESS · SHARPLES VEGETABLE OIL FOOTS PROCESS · SHARPLES TAR DEHYDRATION PROCESS · SHARPLES INSTANT COFFEE PROCESS · SHARPLES TANK-HOUSE EFFLUENT PROCESS · SHARPLES MINERAL OIL REFINING AND RECOVERY PROCESS AND OTHERS.

Super Centrifuge

D-2 Centrifuge


DG-2 Autojector

DV-2 Centrifuge


Super-D-Hydrator

Super-D-Canter

SHARPLES CENTRIFUGES LTD · TOWER WORKS · DOMAN ROAD · CAMBERLEY · SURREY *Tel:* CAMBERLEY 2601

PLANT EQUIPMENT NEWS

tion granulation and intense mixing of both dry and liquid products. It is normally driven by a 25- or 30-hp motor and speeds of up to 4000 rpm are standard. The machine consists essentially of

a chamber, the lower part of which holds interchangeable screens. Eight types of screen in more than sixty sizes are available, ranging from 1¼ in. to 300 mesh. Through the chamber is a shaft carrying a rotor to which a number of hammers, usually swinging, are attached. The mill is normally operated with blades which have one face flat, to have a pulverising action, whilst the other has a knife edge to give a cutting action. Over ten different dual-faced blades are available. The change from knife edge to hammer face is made by reversing the direction of rotation of the rotor, and this involved the design of a universal type of feed throat with a venturi throat having a central feed opening. The precision of its operations derives from the relationship of the screen size to the speed of rotor and type of blade adopted. The output of the mill is about 7500-10,000 lb. an hour, and this high throughput is due to the large screening area in relation to the volume of the grinding chamber. The 180 can be provided with automatic screw feeders, rotary valve powder feeders and vibratory feeders. **Apex Construction Ltd., 15 Soho Square, London, W.1.**

BCE 1816 for further information

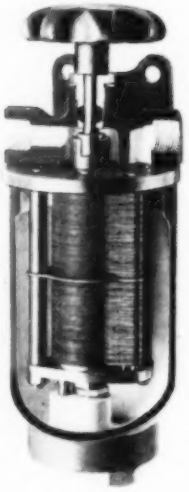
Air and Gas Regulator

Recently introduced is the type 67FR, one of the Fisher series 67 regulators for small volume air or gas flows. It is particularly adapted for instrument air service, supplying 20 psi operating pressure to pneumatic instruments and controllers. It is also a regulator for air spray-guns, air jets and air chucks and cylinders. Constructed of die-cast anodised aluminium, the regulator is suitable for inlet pressures up to 250 psi and will control flows down to zero. It is fitted with an integral relief valve, ceramic filter and moisture drip-pot. The need for piping between these components is eliminated, with consequent saving in time, labour and material when assembling in the field. **The Fisher Governor Co. Ltd., Airport Works, Rochester.**

BCE 1817 for further information

Self-cleaning Filter

Zwicky have just introduced a new range (Zwikleen) of self-cleaning filters. The range is for connections ½ in. to 2 in.; the smaller sizes are either screwed B.S.P. or U.N.F., and the 1¼ in., 1½ in. and 2 in. are flanged. Three stages of filtration may be arranged to give aperture sizes of 0.003, 0.006 and 0.010 in. respectively. The filter body and sump are manufactured in light alloy for the screwed sizes and in cast-iron for the larger flanged type. The internals are manufactured in steel and the filter may be used with the full range of hydrocarbons. The method of filtration is the edge type, the element being built of hollow steel discs, separated by spacers of a given thickness. Steel knives are arranged between the discs in such a way that one full turn of the external handle removes all impurities, which drop into the bottom of the sump. When it becomes necessary to remove the sump for cleaning, the complete element



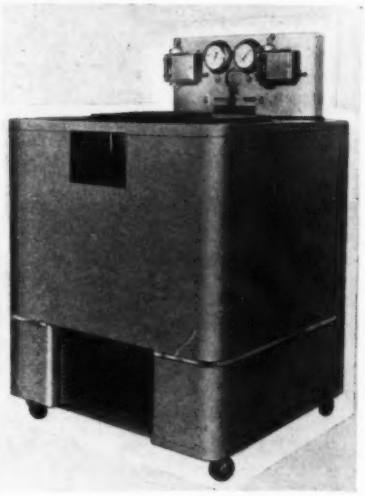
is withdrawn with the sump, thus avoiding mess from the dripping element. **Zwicky Ltd., Slough.**

BCE 1818 for further information

Explosion Suppressor

The Graviner explosion-suppressing apparatus can now be supplied with a cylindrical suppressor vessel for use in vessels, for example, cylinders, where they have been found to be more convenient than the hemispherical-shaped suppressors which hitherto have been employed in all installations. Since the suppressors were made available to civilian industry, twenty-five cases of successful operation (and no failures) have been recorded. The incipient explosions suppressed have been of dusts, including those of wood flour, oat husk, cellulose acetate, arsenious sheep-dip compound and sulphur. **Graviner Manufacturing Co. Ltd., Gosport Road, Gosport.**

BCE 1819 for further information



Low-temperature Cabinets

A versatile range of cabinets that maintain temperatures within the range −100°F to +250°F have been introduced by Lec. The extremely low temperature is made possible by a series of microswitches used in conjunction with small bellows. Advanced engineering methods coupled with compactness and the use of the new refrigerants Arctons 3 and 4 have enabled the manufacturers to employ sealed units which, to the best of their knowledge, is the first time this has been accomplished in Great Britain. All the cabinets are designed for quick pull-down (about three hours), and they are fitted with corrosion-proof liners. **Lec Refrigeration Ltd., Shripney Works, Bognor Regis, Sussex.**

BCE 1820 for further information

Mass Spectrometers

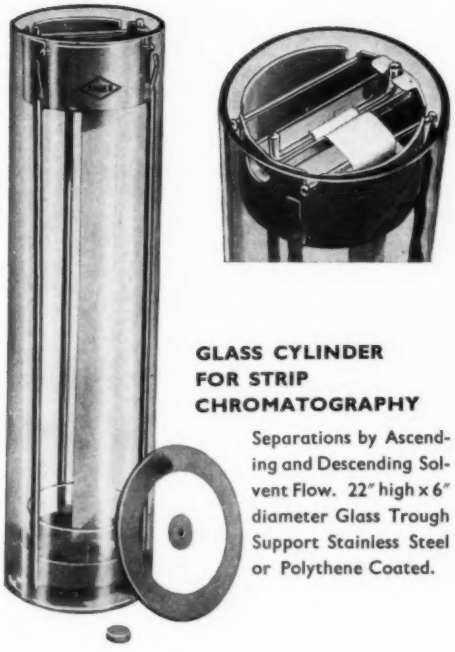
Metropolitan-Vickers have designed two kinds of mass spectrometer for the analysis of inorganic solids. They are the MS7 for the analysis of impurities using the spark ionisation technique, and the MS5 for the determination of isotope ratio using the surface ionisation technique. Prototypes of the MS7 are installed in the research laboratories of Metropolitan-Vickers and B.T.H., and the first production model of the MS5 will soon be going on test. **Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester 17.**

BCE 1821 for further information

Washing Head

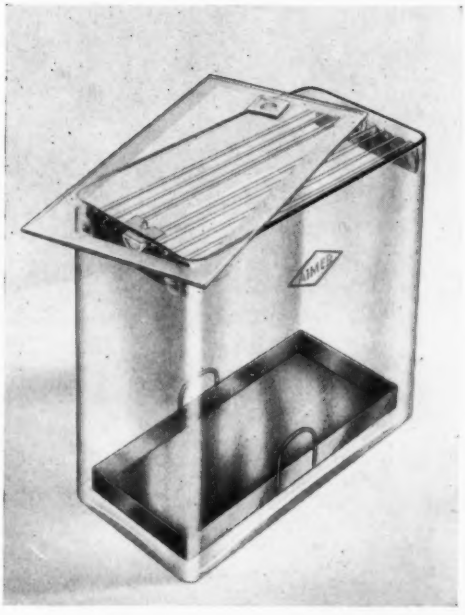
Thorough cleansing of the inside surfaces of tanks up to 20 ft in diameter can be accomplished with a new-type washing head manufactured by H. T. Watson, depending on the liquid pressure available at the nozzle. A unit composed of fifteen radially-disposed nozzles will clean the sides and bottom of a tank: an additional row of six nozzles, inclined upwards, can be fitted at the top to clean the internal top surface of the tank. The nozzles are of the free-passage type and a perforated strainer is incorporated to prevent blockage. The unit is screwed for connection

AIMER for CHROMATOGRAPH Y



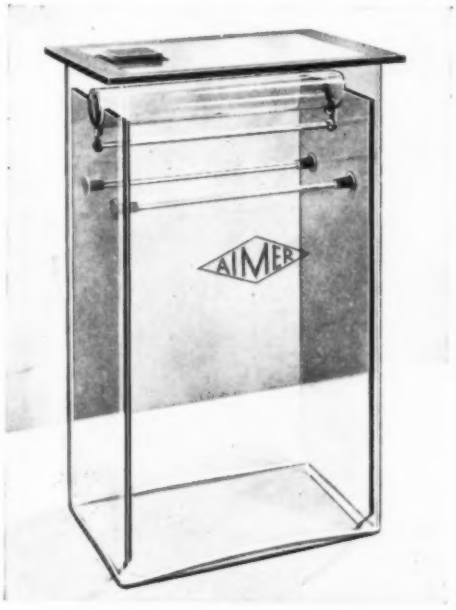
GLASS CYLINDER FOR STRIP CHROMATOGRAPHY

Separations by Ascending and Descending Solvent Flow. 22″ high x 6″ diameter Glass Trough Support Stainless Steel or Polythene Coated.



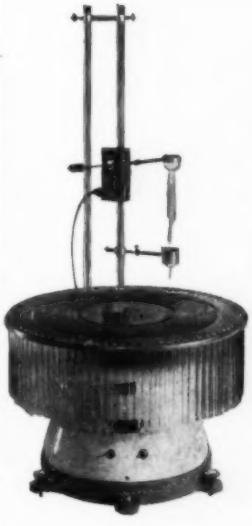
FOR TWO-DIMENSIONAL CHROMATOGRAPHY

For 18½″ x 22½″ paper. All-glass solvent trough. Glass rods, and paper holder supported on polythene coated fitting. Stainless steel tray for upward technique. Can also be supplied with all-glass solvent troughs in place of stainless steel tray at small extra charge.



ALL GLASS CHROMATOGRAPHY TANKS

As developed by the Barnato-Joel Laboratories, Middlesex Hospital Medical School. Complete with all-glass trough and supports movable to any position. Adopting the Busch and Zaffaroni methods on Steroids.



CENTRAL AUTOMATIC FRACTION COLLECTOR

For Column Chromatography. Designed to eliminate drainage errors. Collector plate available in 4 sizes.

OTHER TANK UNITS ALSO SPRAYS, COLUMNS, FILTER PAPERS, ETC.

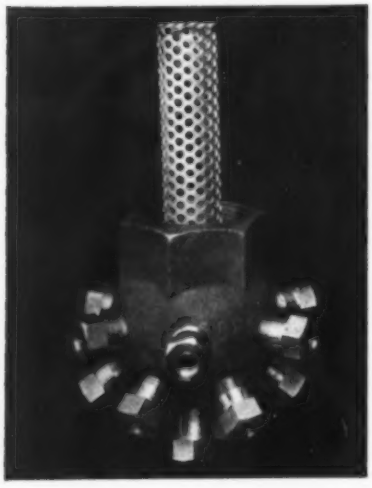
Telephone: GULliver 3618 and 6466

Current illustrated catalogue on request:

AIMER PRODUCTS LIMITED

56/58 ROCHESTER PLACE, CAMDEN ROAD, LONDON, N.W.1

PLANT EQUIPMENT NEWS



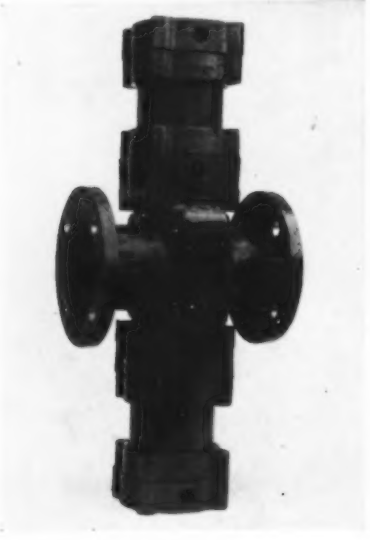
on to a 1½-in. nominal-bore pipe. Standard materials used are brass and 18-8-3 stainless steel. **H. T. Watson Ltd., Croft Street, Widnes, Lancs.**

BCE 1822 for further information

Pinch Valves

Warren Morrison pinch valves are now available for air and electric operation. The basic design consists of a rubber tube with a clamping mechanism, housed in a metallic body. The rubber tube, which isolates the medium handled from the metal body and working parts, is available in a wide range of natural and synthetic rubbers, suitable for a variety of corrosive substances. Designed without protrusions or pockets, it provides a straight-through unobstructed flow, thereby eliminating clogging and reducing wear when handling abrasives. Two designs of air-operated pinch valves are now in production, one for on/off duties and a newly-introduced design providing flow control. **Warren Morrison Ltd., 29 Bury Street, London, S.W.1.**

BCE 1823 for further information



Other Items

New safety goggles with acetate replaceable lenses designed to deflect flying particles and allow a wide field of vision are now available from **Safety Service Co., 34a Stonebridge Park, London, N.W.10.**

BCE 1824 for further information

Wolf Electric Tools Ltd. have added two new models to their range of electric drills. These are the Wolf ¼-in. general-duty drill, Type OK2c, and the De Luxe, Type KG2c. The OK2c is recommended for all continuous light production and general-duty work, and the model complies with the latest B.S.S. for portable electric tools No. 2769. The KG2c *de luxe* model is provided with a heavy-duty, geared-type chuck to which is added a neat steel chuck shroud for the operator's protection. **Wolf Electric Tools Ltd., Hanger Lane, London, W.5.**

BCE 1825 for further information

SEEN AT THE PLASTICS EXHIBITION

Plastic Pipe

Chemidus showed the newest addition to their range of rigid plastic pipe, HI-20, which is manufactured from rigid PVC modified to give high shock resistance. Its chemical resistance is a little less than the company's "2000" product, and it is intended for use where higher shock resistance is of prime importance. The product is opaque and has a specific gravity of 1.37 and a maximum tensile strength of 5750-6000 psi. Its impact strength is (ft lb./in. notch) Charpy 2¼-3¼ and Izod 10-20. **Chemidus Plastics Ltd., Dominion Buildings, South Place, London, E.C.2.**

BCE 1826 for further information

Anti-static Plasticiser

A new member of the Bisoflex range of plasticisers which has anti-static properties and is said to be particularly useful at low temperatures was demonstrated by **The Distillers Co. Ltd., Devonshire House, Piccadilly, London, W.1.**

BCE 1827 for further information

Reinforced Sheet

Cobex vinyl sheet reinforced with expanded metal was shown by B.X. Plastics. The new product is in the form of a laminate, and the sheeting on either side of the metal support may be of rigid or flexible plastic to suit the needs of a particular application. The laminate is expected to be of special use in tanks and similar pieces of chemical plant, and it was demonstrated as a tank fabrication on a full-scale working model. **B.X. Plastics Ltd., Higham Station Avenue, London, E.4.**

BCE 1828 for further information

Foamed Ball-cocks

A new, cellular, rigid PVC, Fi-Vi, composed, it is said, of extremely small cells was shown by Whiffen. Applications include thermal insulation, shock resistance and the fabrication of ball-cock floats. It is claimed that the floats retain their buoyancy even if severely punctured, and that they possess great chemical resistance. **Whiffen & Son Ltd., 95 Wigmore Street, London, W.1.**

BCE 1829 for further information

Chemical Ware

Among the range of chemical ware shown by Airothene was an improved plastic drum-tap, model K. The exhibitors announced that they are making to special order liquid storage drums of 50 gallons capacity fitted with snap-on covers and ¾-in. taps. **Airothene Ltd., 254 Euston Road, London, N.W.1.**

BCE 1830 for further information

New Mouldings

A range of seamless polythene containers, drum liners and rigid self-standing tanks manufactured by the Engel process was exhibited by the sole operators of the process in Great Britain **The Rosedale Group of Companies, 11 Upper Grosvenor Street, London, W.1.**

BCE 1831 for further information

High-impact Fittings

Extrudex showed a range of moulded fittings for piping constructed of high-impact PVC. They announced that they were making tubes of unplasticised polythene of diameter up to 15 in.—the biggest, they claim, being manufactured in Europe. **Extrudex Ltd., Western Road, Bracknell, Berks.**

BCE 1832 for further information

Polythene-lined Pipes

New products shown by Yorkshire Copper Works included polythene-lined steel pipes and polythene-covered copper tubes. **The Yorkshire Copper Works Ltd., Leeds.**

BCE 1833 for further information

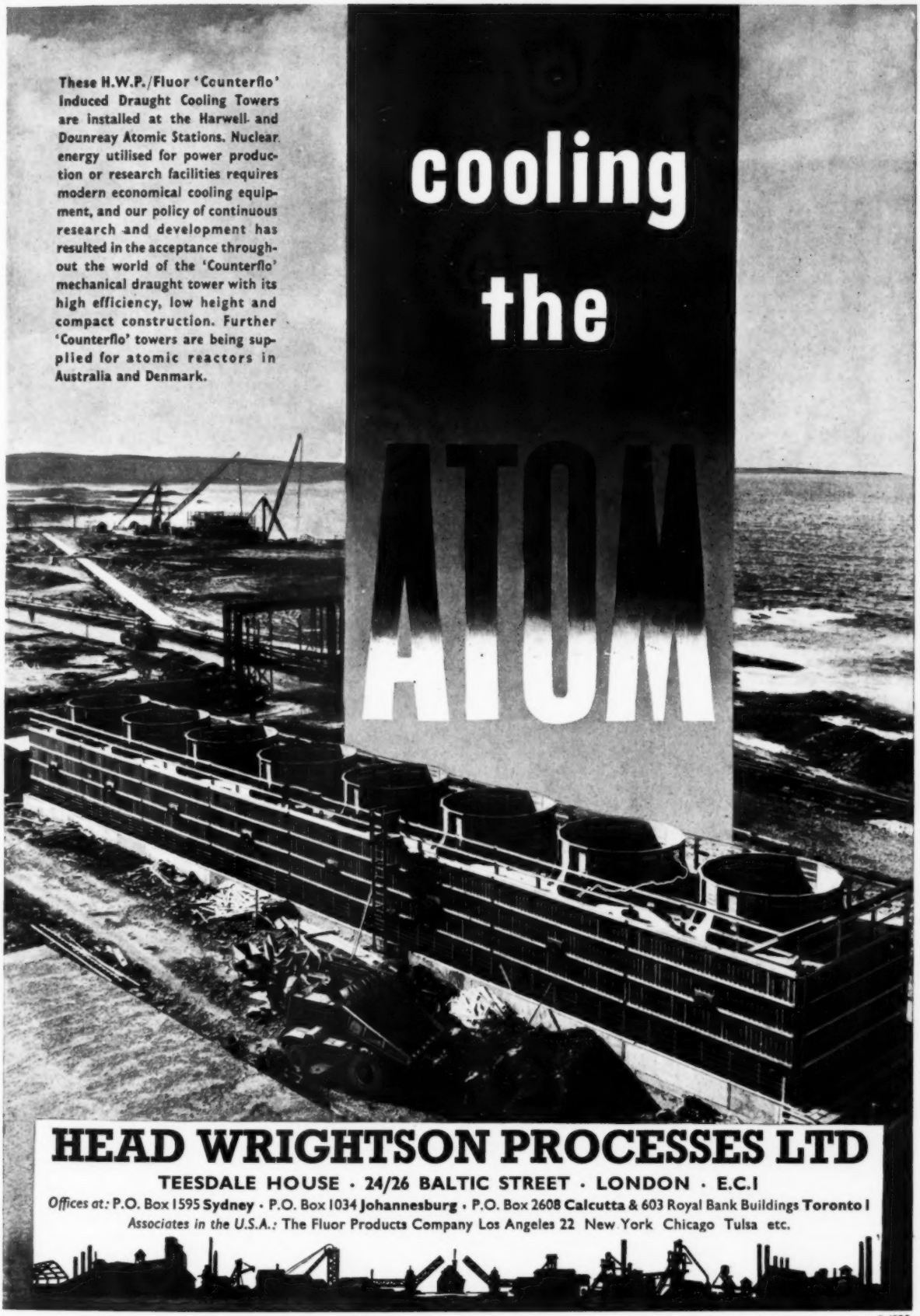
Range of Mills

The Type V four-toothed disc mill shown by Industrial Plastics is one of the range of the Condux milling plant now available in Britain solely through their agency, recently acquired. **Industrial Plastics Ltd., 93 Regent Street, London, W.1.**

BCE 1834 for further information

Foamed Insulator

Phenfoam, a foamed polystyrene, was exhibited by Phoenix Rubber. As a heat insulator it can withstand temperatures


These H.W.P./Fluor 'Counterflo' Induced Draught Cooling Towers are installed at the Harwell and Dounreay Atomic Stations. Nuclear energy utilised for power production or research facilities requires modern economical cooling equipment, and our policy of continuous research and development has resulted in the acceptance throughout the world of the 'Counterflo' mechanical draught tower with its high efficiency, low height and compact construction. Further 'Counterflo' towers are being supplied for atomic reactors in Australia and Denmark.
cooling
the
ATOM
HEAD WRIGHTSON PROCESSES LTD
TEESDALE HOUSE · 24/26 BALTIC STREET · LONDON · E.C.1
Offices at: P.O. Box 1595 Sydney · P.O. Box 1034 Johannesburg · P.O. Box 2608 Calcutta & 603 Royal Bank Buildings Toronto 1
Associates in the U.S.A.: The Fluor Products Company Los Angeles 22 New York Chicago Tulsa etc.

P 4995

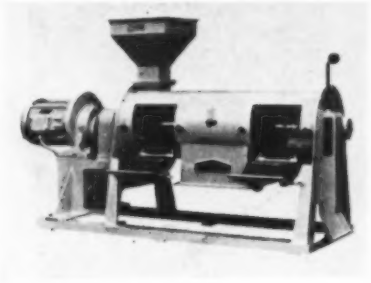
PLANT EQUIPMENT NEWS

up to 70°C, but modifications are expected to be made to enable the maximum temperature to be 90°C. The material is colourless and is said to be non-toxic, impervious to insects or fungi and to absorb practically no water or water vapour. It is covered during manufacture with a tough skin which can be coated if necessary. Full-scale delivery is expected to commence in October. **Phoenix Rubber Co. Ltd., 91 Bishopsgate, London, E.C.2.**

BCE 1835 for further information

Batch and Continuous Mixer

Prototype models of batch and continuous Lödige-Morton mixers now being made under licence from Lödige, Germany, were shown by Morton Machines. The mixers incorporate double plough-shaped shovels which



rotate inside a horizontal mixing drum, filled to 60% capacity. The mix is picked up and projected into free space to mingle with other particles and to fall back for re-mixing. Mixing times as short as 1 to 6 minutes are normal, it is said, with dry materials. When mixing materials of very different densities, the vessel is caused also to rotate. The batch mixers are made in the capacity range ¼-1050 gallons, and the continuous mixers in the range 8-880 gallons. **Morton Machine Co. Ltd., Wishaw.**

BCE 1836 for further information

New Publications

No single catalogue could do justice to the extensive range of equipment manufactured by Boultons for the ceramic and other process industries. However, their latest edition is a worthy successor and holds something of interest for all engineers. The last few pages have been devoted to technical data which, alone, makes the catalogue a handy source of reference. **William Boulton Ltd., Burslem, Stoke-on-Trent.**

BCE 1837 for further information

Visco have recently released a new brochure (574) on "Modern Dust Collection". This supersedes No. 532, "Modern Dust Collection and Fume Removal". Copies from **The Visco Engineering Co Ltd., Stafford Road, Croydon.**

BCE 1838 for further information

"Instrumentation and Automatic Control of Soaking Pits" is the title of a new Kent publication (No. 2021). It details a typical control scheme for a gas- and/or oil-fired soaking pit, although Kent hasten to point out that they can offer complete instrumentation for all types of soaking pit and fuels used. **George Kent Ltd., Luton, Bedfordshire.**

BCE 1839 for further information

Accles & Pollock have just issued an up-to-date catalogue (Tubular Sections) covering the company's seamless steel tubes. **Accles & Pollock Ltd., Oldbury, Birmingham.**

BCE 1840 for further information

A new bulletin on the sizes and types of Oxythene Duoply laminated PVC ducting which they can normally supply from stock has recently been published by **Horwitch-Smith & Co Ltd., 42 Lower Loveday Street, Birmingham, 19.**

BCE 1841 for further information

A 24-page booklet describing their range of industrial high-vacuum pumps has been announced by **Edwards High Vacuum Ltd., Manor Royal, Crawley, Sussex.**

BCE 1842 for further information

Isopad's new catalogue on laboratory mantles has recently been received. Copies from **Isopad Ltd., Barnet By-Pass, Boreham Wood. Hertfordshire.**

BCE 1843 for further information

A publication (No. 3604) illustrating pictorially the most important methods used in localised exhaust ventilation has been issued by **Sturtevant Engineering Co. Ltd., Cannon Street, London, E.C.4.**

BCE 1844 for further information

A selection of subjects included in their wide range of stainless-steel plant is given in the latest publication (Plant and Equipment) now being issued by **A. J. Riley & Son Ltd., Batley, Yorkshire.**

BCE 1845 for further information

A descriptive leaflet on Kanigin plate, a new hard and corrosion-resistant metallic coating, has been published by **Albright & Wilson (Mfg.) Ltd., 1 Knightsbridge Green, London, S.W.1.**

BCE 1846 for further information

A fork-lift truck attachment handbook for users has just been published by **R. H. Corbett & Co. Ltd., Burgess Hill, Sussex.**

BCE 1847 for further information

Details of the recently-introduced R.50 air filter unit are contained in a new leaflet by **Fibreglass Ltd., Ravenhead, St. Helens, Lancashire.**

BCE 1848 for further information

"Sankey's Heat and Acid Resisting Materials" is the title of a new leaflet giving details of the company's fire cements, firebricks and fire clays, foundry materials and acid- and alkali-resisting materials. **J. H. Sankey & Son Ltd., Ilford, Essex.**

BCE 1849 for further information

A technical report on progress made in the production of "Irradiated Polythene Tape", together with details of its properties and applications, has recently been released by **Tube Investments Ltd., The Adelphi, London, W.C.2.**

BCE 1850 for further information

Specification sheets covering a number of transducers and their associated power units, and the company's simple analogue computer, have recently been announced by **Evershed & Vignoles Ltd., Chiswick, London, W.4.**

BCE 1851 for further information

Publication E-1000 gives applications and details of Muirhead Magslips. These versatile instruments can provide for remote indication or control at one or more points. **Muirhead & Co. Ltd., Beckenham, Kent.**

BCE 1852 for further information

A publication recently received gives details of the properties of aluminium bronze, its wear resistance, corrosion resistance, design of castings, etc. Copies from **Fry's Diecastings Ltd., Brierley Hill Road, Wordsley, Stourbridge.**

BCE 1853 for further information

A brochure containing complete descriptions of their model Super RV7, RV14 and jar-feeding attachment has been announced by **Flexile Metals Co. Ltd., 796 Holloway Road, London, N.19.**

BCE 1854 for further information

A tastefully-produced publication entitled "Engineering in Courtaulds" has recently been issued. This surveys the work of Courtaulds' engineering division and does so in a manner which will warrant the close attention of those interested in the varied opportunities Courtaulds offer for a career in man-made fibres. **Courtaulds Ltd., 16 St. Martin's-le-Grand, London, E.C.1.**

BCE 1855 for further information

Technical information on "Brimor" high-temperatures cements is contained in a recent publication by **The Morgan Crucible Co. Ltd., Battersea Church Road, Battersea, London, S.W.11.**

BCE 1856 for further information

B.S. 2856: 1957 (3s. 6d.) details a standard procedure which gives the essential accuracy required for precise dimensional inter-changeability on engineering drawing. **British Standards Institution, 2 Park Street, London, W.1.**

BCE 1857 for further information

DRAWING OFFICE EFFICIENCY

Hundreds of drawing offices in this country have been equipped with Mason and Arclight drafting units of one kind or another. The range of equipment has been designed to meet every drawing office requirement, and whichever type of unit is selected, 100 per cent efficiency with space and movement saving characteristics will result. The Mason Planned Drawing Office Service is available, without obligation, to all who are contemplating the equipping of new or existing offices and extensions.

E. N. MASON & SONS LTD.

Arclight Works, Colchester, Essex. Telephone: Colchester 5191
291-3 High Holborn, London, W.C.1. Telephone: CHA. 6411
13-15 St. Vincent Place, Glasgow, C.1. Telephone: Cen. 2775
8-10 Newton Street, Manchester, 1. Telephone: Cen. 9221
51 Victoria Street, Sheffield, 1. Telephone: Sheffield 21776
6 Britannia House, Wellington Street, Leeds, 1. Telephone: Leeds 23537
3 Unity Street, Bristol, 1. Telephone: Bristol 26986

NUTREGEN
Superfine
WHEAT STARCH

For all industrial and food manufacturing purposes

SAMPLES and QUOTATIONS on request

NUTREGEN LTD

65 POUND LANE, LONDON N.W.10

Telephone : Willesden 6644

SPRAYCONE and FANJET *Nozzles*

FOR EVERY INDUSTRIAL USE Various chemical processes demand different types of nozzles. Illustrated are cone sprays and flat sprays. Many variations are available—let us make recommendations. *Write for Catalogue*

H·T·Watson & Co. Ltd.

CROFT ST · WIDNES · ENGLAND

Phone: WIDNES 2313 *Grams*: WATSON WIDNES

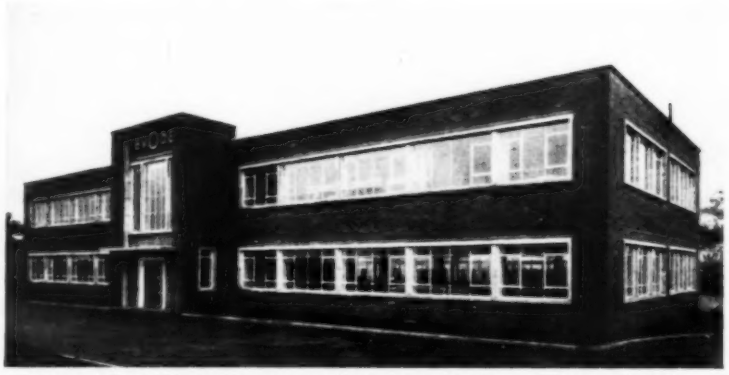
Month's News in Brief

The B.P. Exploration Co., in conjunction with I.C.I., have restarted test drilling for natural gas in the Eskdale area of North Yorkshire. Two previous wells—one drilled before the last war, the other in 1954—found some gas at Eskdale. The purpose of the well now being drilled is to determine as far as possible the extent of this potential gas field and to estimate whether sufficient gas is present to justify the cost of building a pipe-line to carry it to I.C.I.'s works at Billingham and Wilton on Tees-side. At the time of going to press, drilling had reached a depth of around 3000 ft, and it was expected that a further 500 ft would have to be drilled before a full assessment of the well could be made. The well being drilled by B.P. and I.C.I. is quite distinct from that being undertaken by B.P. on behalf of the Gas Council.

Now established as one of the country's leading manufacturers of building chemicals and industrial adhesives and polishes, Evode Ltd., of Stafford, a company which places great emphasis on research has celebrated its twenty-fifth anniversary by moving its headquarters into an impressive two-storey office and laboratory block at Common Road, Stafford. This is the dominant building (see accompanying illustration) of a group already completed on a nine acre site, and among its most striking features are the imaginatively designed and equipped research laboratories. Evode specialises in coatings designed to withstand industrial corrosion. Already in production on a new site is what Evode claims as one of the most modern plants for producing bituminous emulsions and spirit-bound bitumens.

Foster Wheeler Ltd. have recently been awarded a further contract by the Government Oil Refineries Administration for the expansion of their Daura refinery. The value of the contract is approximately £3,700,000 and the work will be completed within two years. The additional plant will almost double the present throughput of Daura refinery and the ultimate throughput of 48,000 BPSD will more than meet Iraq's increasing demands for gasoline, kerosene and fuel oils during the next few years. The type of reforming unit selected is an Esso Research & Engineering Co.'s Powerformer, have a capacity of 5000 BPSD. This process is of the most up-to-date design and will enable 100-octane grade gasoline to be produced.

An exhibition in honour of the bicentenary of the birth on August 9, 1757, of Thomas Telford, the great civil engineer, was opened by Lord Mills, Minister of Power, on July 22. At the exhibition, which closed on August 10, one of the largest canvases in London, measuring 24 ft by 11 ft 6 in. and painted by Mr. Leonard Rosoman, depicted a romantic landscape in which were portrayed many of Telford's more famous works. Telford had the distinction of being the first President of the Institution of Civil Engineers, at whose premises the exhibition was held.



Evode Ltd.'s impressive new company headquarters and laboratory block at Stafford.

A.P.V. have concluded an agreement with the Rosenblad Co., of Stockholm, for the exclusive manufacture and sale of the Rosenblad heat exchanger in Great Britain. A.P.V. will also be responsible for its sale in the Commonwealth, except Canada, and in the Middle East. The manufacturing and selling rights were previously held by Ashmore, Benson, Pease & Co. Ltd.

The Isotope School at Harwell is arranging a three-day course from September 25 to 27, 1957, for directors and senior executives from industry to enable them to hear about and discuss the limitless uses to which radio-isotopes can be put. Forms of application and further information about the course are available from The Registrar, Isotope School, Atomic Energy Research Establishment, Harwell, Berks.

Borax Consolidated Ltd. are now marketing crystalline elemental boron in the pure state (99.0% to 99.7%) which is expected to be of great interest to the metallurgical and electrical industries, and also for certain nuclear energy applications. The new product has a low oxygen and nitrogen content, making it particularly suitable for incorporation into alloys.

The Hawker Siddeley Group Ltd. and John Brown & Co. Ltd. have formed a new company known as Hawker Siddeley John Brown Nuclear Construction Ltd. (with a capital of £500,000), in which Hawker Siddeley and John Brown are equal partners. The directors of the new company are: Sir Roy Dobson (chairman); Sir Arnold Hall; Sir William Farren; Mr. E. P. Hawthorn; Sir Stanley Rawson; Mr. Eric Mensforth; Mr. R. J. Barclay; and Mr. V. A. Pask.

Horwitch-Smith & Co. Ltd. have re-equipped their works at Birmingham as a result of which the company can now give demonstrations of the Knapsack-Griesheim whirl sinter equipment, flame spraying of all types of polymers, the spraying of PVC spraysols and the dip application of PVC plastisols and plexigels.

The London and Home Counties Regional Advisory Council for Higher Technological Education have recently released their "Bulletin of Special Courses in Higher Technology" for 1957-8, Part 1. Copies from the Secretary, Regional Advisory Council, Tavistock House South, Tavistock Square, London, W.C.1. Price 3s. each copy, post free.

Bristol Aircraft have announced that they are setting up a plant to manufacture resin-impregnated glass pipe of diameters up to 3 ft. The length will depend on the space available in the factory.

Aldridge Plastics Ltd., Staffordshire, have announced an ambitious expansion programme which they say will multiply their early 1957 production capacity of ¼ million mouldings a week by several hundred per cent during the next two or three years.

Chemical Construction (Great Britain) Ltd. announce that they have received an additional contract from British Titan Products Co. Ltd., for a sulphur-burning contact sulphuric acid plant.

Flexile Metal Co. Ltd. have announced that from August 5 their registered offices will be at their new factory at Bessemer Drive, Stevenage, Herts.

I.C.I. have given £25,000 to Sheffield University towards the cost of building extensions to the departments of chemical engineering, chemistry and fuel technology.

Turner Manufacturing Co. Ltd., of Wolverhampton, have formed a subsidiary company, Hydraulics & Pneumatics Ltd., for the manufacture of hydraulics and pneumatics for general industrial requirements.

Auto Diesels Ltd. have recently been elected members of the Council of British Manufacturers of Petroleum Equipment.

Humphreys & Glasgow of Canada have been awarded the contract to build the new chlorine caustic soda unit of Dow Chemicals of Canada at Dow's Sarnia Plant.

sound engineering and efficiency sells MIKRO air locks

The illustration shows the first batch of 66 Direct Coupled Units ordered by one of our users.

Manufactured in Sizes 5" 8" 12" 18" 24" diameters.
Cast Iron, Stainless Steel and Non Ferrous Alloys.
Temperatures up to 250°C.
DRIVES: BELT, DIRECT COUPLED, VARIABLE SPEED IF REQUIRED.

We can offer a choice of flexible Rotor Vanes i.e Vitrathene, Silicon Rubber, Fluon and Solid Steel.
Enquiries with density of material to be handled, temperatures and system pressures to:-

MIKRO-PULVERISER (FINE)
MIKRO-ATOMISER (ULTRA FINE)
MIKRO-FILTER UNIT (100 PER CENT)
REG. U.S. PAT. OFF.

BRAMIGK & CO. LTD.
ENGINEERS

Mikro House, 15 Creechurch Lane, London, E.C.3. Telephone: AVEnue 4822—4825

Exclusive Manufacturing Licencees for Pulverising Division, Metals Disintegrating Company Inc., Summit, New Jersey, U.S.A.

Forthcoming Events

Home

August 29. *The 21st Engineering, Marine and Welding and Foundry Trades Exhibition:* At Olympia, London, until September 12.

September 4. *Annual meeting of the British Association for the Advancement of Science:* At Dublin, until September 11.

Overseas

August 25. *Meeting of the American Association for the Advancement of Science—Pacific Division:* At Stanford, California, until August 27.

August 26. *The 5th International Congress on Low-temperature Physics and Chemistry:* At Madison, Wisconsin, until August 31.

September 6. *British Trade Fair and Exhibition:* At Helsinki, Finland, until September 22.

September 8. *The 132nd meeting of the American Chemical Society:* At New York, until September 13.

September 8. *The 6th Empire Mining and Metallurgical Congress:* At Vancouver, Canada, until October 9.

September 9. *International Conference on Radio-isotopes in Scientific Research:* At Paris, France, until September 20.

September 9. *International Congress on Nuclear Structure:* At Rheovath, Israel, until September 13.

September 12. *The 17th International Congress of Pharmaceutical Sciences:* At Leiden, Netherlands, until September 14.

September 13. *International Plastics Fair:* At Amsterdam, Netherlands, until September 20.

September 16. *The 3rd International Conference on Engineering Education and Training:* At Paris, France, until September 20.

September 17. *International Congress on Industrial Chemistry:* At Athens, Greece, until September 24.

September 18. *Symposium on the Formation and Stabilisation of Free Radicals:* At the East Building Lecture Room, National Bureau of Standards, Washington, D.C., until September 20.

Events for 1958

The London Section Exhibition Committee of the Oil and Colour Chemists' Association has announced that the preliminary arrangements for the Tenth Technical Exhibition, 1958, have now been completed. The venue will once again be the New Hall of the Royal Horticultural Society at Greycoat and Elverton Streets, London, S.W.1. The exhibition will take place on **March 11, 12 and 13,** 1958. Further details from the General Secretary, R. H. Hamblin, Memorial Hall, Farringdon Street, London, E.C.4.

Belgium's first universal and international exhibition since the war will be held in Brussels from **April 17 to October 19,** 1958. Oragnisers are British Overseas Fairs Ltd., 21 Tothill Street, London, S.W.1.

A symposium on the organisation of chemical engineering projects is planned for **June 24.** Being organised by the Institution of Chemical Engineers (16 Belgrave Square, London, S.W.1), from whom further details may be obtained. The symposium will last until **June 26.**

A symposium on microchemistry will be held in the University of Birmingham over the period **August 20 to 27,** 1958, both dates inclusive. This symposium will be held under the auspices of the Society for Analytical Chemistry and is being organised by the Midlands Section and Microchemistry Group. Registration forms and further information may be obtained on application to the Symposium Secretary, W. T. Elwell, F.R.I.C., I.C.I. (Metals Division) Ltd., P.O. Box No. 216, Research Department, Kynoch Works, Witton, Birmingham, 6.

The Electronic Computer Exhibition, to be held at Olympia, London, from **November 28 to December 4,** 1958, will be the first of its kind in Great Britain. It is being sponsored by a joint committee of the Radio Communication and Electronic Engineering Association and the Office Appliance and Business Equipment Trades Association. The exhibition is non-profit making and any excess of receipts over expenditure is to be returned to exhibitors. The exhibition director is Mrs. S. S. Elliott, 11 Dowgate Hill, London, E.C.4.

People in the News

The President of the Board of Trade has appointed **Mr. W. R. Black** chairman of the National Research Development Corporation in succession to the late chairman, Sir Alan Saunders, who died in February. Mr. Black is managing director of Associated Commercial Vehicles Ltd., and has for many years played a prominent part in the motor industry.

Mr. E. Markham, director and sales manager of Peter Brotherhood Ltd., was installed as president of the Whitworth Society on June 14 last. It is a condition of membership of the Society that a Whitworth Award be held signifying practical and technical ability in engineering. Mr. Markham gained his Whitworth Exhibition in 1915 as a pupil of Sunderland Technical College. Mr. Markham, at 62, is one of the youngest members to hold the office of presidency of the Whitworth Society.

Sharples Chemical & Industrial Ltd. announce the appointment of **Dr. Alan J. Hayter** as a director of the company. Other appointments announced by Sharples are: **Mr. W. Maxfield** as senior project engineer (Scotland and Northern Ireland); **Mr. R. S. Curwen** as senior project Engineer (South-east England); and **Mr. F. V. Hooley**, who has joined Sharples' head office applications engineering staff at Camberley.

Dr. A. J. Hayter.

G. W. M. Lush.

Mr. V. E. Baker has been appointed a commercial director and **Mr. E. G. Reynolds** as works director of Amber Oils Ltd.

Birfield announce the formation of a new subsidiary company, Birfield Engineering Ltd., whose special function is to be the co-ordination of engineering activities among the companies that make up the Birfield group. The managing director of Birfield Engineering Ltd. will be **Mr. G. W. M. Lush. Mr. D. Bastow** and **Mr. E. J. Rabson** will also be directors of the new company, whose headquarters will be in Chester Road, Birmingham, as soon as building is completed.

Marshal of the Royal Air Force, Lord Tedder (right), is conducted round the new metallurgical laboratory of the British Welding Research Association, Abington Hall, Cambridgeshire, by Dr. R. Weck, research director. Lord Tedder performed the inaugural ceremony by cutting, with a welding torch, a tape obstructing the entrance to the new building. (See Digest this issue.)

Dr. M. A. Phillips has been appointed managing director of a new company, Southern Chemical Plant Co. Ltd., the registered address of which is 56 to 60 Islington Park Street, London, N.1. The new company plans to design, acquire and install chemical plant for the process industries.

The Micronizer

for grinding to micron sizes

IS FLEXIBLE

It grinds dry solids to sub-sieve sizes and the lower micron ranges. It handles small quantities of valuable materials or large tonnages of commercial products.

IS VERSATILE

It handles with equal success materials that are heat-sensitive or very hard substances.

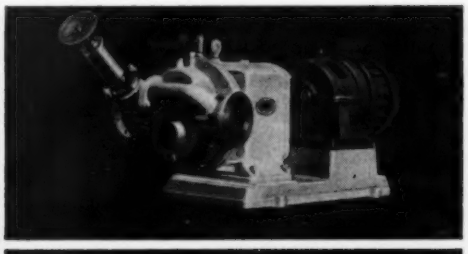
IS ORIGINAL

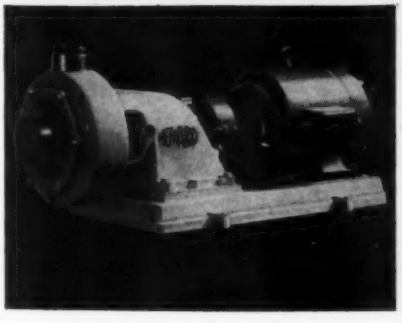
It does a job where conventional grinding methods cannot be employed and achieves high-speed reduction to the micron particle size distribution required.

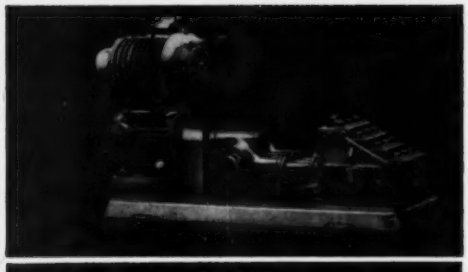
Micronizer Mills or complete installations produced to customers' requirements.

Commission micronizing undertaken at our plant near St. Albans, Herts.

F. W. BERK & Co., Ltd. Micronizer Plant Dept.,
1/19, New Oxford Street, London, W.C.1
Tel.: MUSeum 0934







WHAT ARE YOUR SPECIAL NEEDS?

Robust construction • Simple maintenance & cleaning
Must resist corrosion • Could be steam-jacketed?
Economical running • Handle high V.I. material

HOWARD 'M' TYPE ROTARY PUMP
Handles delicate materials—even those with high V.I.—without agitation or contamination. Designed for easy stripping and cleaning. Seven sizes offering up to 15,000 g.p.h. for heads up to 200 ft.

HOWARD PROPORTIOMETER PUMP*
A robustly constructed variable output plunger pump. The simple control device permits adjustment from zero to maximum output while the pump is running or stationary. Eight sizes offering a maximum capacity of 2,000 g.p.h. and for pressures of up to 12,000 p.s.i.

**Made under Moore & Charlton Patents No. 476953 & 500569*

HOWARD TRIPLEX PUMP
A fixed capacity pump designed to offer a smooth and pulseless flow against high pressures. Special liquid ends can be fitted if required. Made in three sizes (5, 10 and 20 h.p.) afford a maximum capacity of 6,000 g.p.h. for pressures up to 12,000 p.s.i.

HOWARD CENTRIFUGAL PUMP
Single stage, high pressure pump with circular casing, external heavy duty bearings. Two basic models—FOR CHEMICALS: a normal centrifugal pump with closed impellor, and flanged connections. For FOOD: Internal parts machined all over and specially arranged for easy cleaning. Capacities range up to 250 g.p.m. for heads up to 140 p.s.i.

Whatever they are we may be able to help

Howard

For further information, please write to :—
HOWARD PNEUMATIC ENGINEERING CO. LTD.,
FORT ROAD, EASTBOURNE. TEL: EASTBOURNE 1179
TELEGRAMS AND CABLES: HOWMATIC, EASTBOURNE

BCE 1805 for further information

INDEX TO ADVERTISERS

Acalor (1948) Ltd.	18
Aimer Products Ltd.	517
Alfa-Laval Co. Ltd.	17
Allen, Edgar, & Co. Ltd.	29
Allen, W. G., & Sons (Tipton) Ltd.	7
Allspeeds Ltd.	26
A.P.V. Co. Ltd., The	472
Automotive Products Co. Ltd.	August
Badger, E. B., & Sons Ltd.	August
Berk, F. W., & Co. Ltd.	63
Birlec Ltd.	July
Birmingham & Blackburn Construction Co. Ltd.	36
Birwelco Ltd.	41
Bivac Air Co. Ltd.	June
Blackwood Hodge, John, & Co. Ltd.	23
Booth, John, & Sons (Bolton) Ltd.	August
Braby, Fredk., & Co. Ltd.	25
Bramigk & Co. Ltd.	523
British Acheson Electrodes Ltd.	38
British Arca Regulators Ltd.	35
British Geon Ltd.	33
British Industrial Engineering Co. (Staffs.) Ltd.	August
British Labour Pump Co. Ltd.	471
British Oxygen Linde Ltd.	August
Broadbent, Thomas, & Sons Ltd.	4
Brotherhood, Peter, Ltd.	32
B.S.A. Tools Ltd.	2
Burnett & Rolfe Ltd.	August
Butterfield, W. P., Ltd.	July
Butterley Co. Ltd., The	13
Butterworths Scientific Publications	August
Calmic Engineering Co Ltd	37
Camrex Paint Ltd.	36
Candy Filter Co. Ltd., The	July
Chapman & Hall Ltd.	513
Chemical Engineering Construction (Pensnett) Ltd.	54
Chemical Engineering Wiltons Ltd.	July
Constable & Co. Ltd.	513
Costain-John Brown Ltd.	August
Crofts (Egnineers) Ltd.	August
C.T. (London) Ltd.	August
Cyclops Engineering Co. Ltd., The	53
Danks of Netherton Ltd.	August
Davey, Paxman & Co. Ltd.	43
Distillers Co. Ltd., The	11
Donovan Electrical Co. Ltd.	56
Douglas, William, & Sons Ltd.	August
Doulton Industrial Porcelains Ltd.	August
Electrical Power Engineering Co (B'ham) Ltd.	August
Electro-Chemical Engineering Co. Ltd.	August
Electro-Hydraulics Ltd.	58
Electroflo Meters Co. Ltd.	August
Elliott Bros. (London) Ltd.	46
Enamelled Metal Products Corporation (1933) Ltd.	July
England, Hughes, Bell & Co. Ltd.	50
English Electric Co. Ltd., The	August
English Glass Co. Ltd., The	August
Evans, Joseph, & Sons (Wolverhampton) Ltd.	8
Extrudex Ltd.	55
Extrusionwork Ltd.	August
Fibreglass Ltd.	August
Film Cooling Towers (1925) Ltd.	August
Foster Wheeler Ltd.	August
Fraser, W. J., & Co. Ltd.	1
General Descaling Co. Ltd.	Cover 4
General Engineering Co. (Radcliffe) Ltd.	32
General Refractories Ltd.	August
Girdlestone Pumps Ltd.	August
Giusti, T., & Son Ltd.	August
Globe Pneumatic Engineering Co. Ltd.	57
Graviner Manufacturing Co. Ltd.	24
Graviner Manufacturing Co. Ltd. (Colnbrook)	August
Harris (Birmingham), F. & R. M., Ltd.	51
Harvey, G. A., & Co. (London) Ltd.	19
Haworth (A.R.C.), F., Ltd.	42
Head Wrightson Processes Ltd.	519
High-Pressure Components Ltd.	54
Hilger & Watts Ltd.	August
Holmes, W. C., & Co. Ltd.	August
Horseley Bridge & Thomas Piggott Ltd.	27
Howard Pneumatic Engineering Co. Ltd.	63
Humphreys & Glasgow Ltd.	August
Huntington, Heberlein & Co. Ltd.	34
Hygrotherm Engineering Ltd.	August
Imperial Chemical Industries Ltd.	9
Industrial Descaling Tools Ltd.	August
Industrial Fan & Heater Co. Ltd.	August
Johnson, S. H., & Co. Ltd.	August
Kek Ltd.	6
Kingsbourne Products Ltd.	52
Lacy-Hulbert & Co. Ltd.	August
Langleys Alloys Ltd.	30
Lincoln Electric Ltd.	5
Londex Ltd.	August
Madan, Charles S., & Co. Ltd.	24
Marston Excelsior Ltd.	August
Mason, E. N., & Sons Ltd.	521
Megator Pumps & Compressors Ltd.	August
Meigh Castings Ltd.	50
Midland Heating & Ventilating Co. Ltd.	14
Mills Packard Construction Co. Ltd.	55
Mitchell, L. A., Ltd.	August
Mono Pumps Ltd.	51
Morton Machine Co. Ltd.	August
Mountford (Birmingham), Fredk., Ltd.	August
Murex Ltd.	48
Newton, Chambers & Co. Ltd.	16
Nordac Ltd.	44
Northide Ltd.	50
Norton & Riding (Yorkshire) Ltd.	58
Nutregen Ltd.	521
Odoni, Alfred A., & Co. Ltd.	8
Openshaw, William, Ltd.	July
Ormerod Engineers Ltd.	22
Owl Engineering Supplies Ltd.	Cover 2
Piscall Engineering Co. Ltd., The	54
Peabody Ltd.	57
Podmore, Wm., & Sons Ltd.	59
Pontifex, H., & Sons Ltd.	22
Powell Duffryn Carbon Products Ltd.	August
Power-Gas Corporation Ltd., The	August
Premier Colloid Mills Ltd.	July
Procon (Great Britain) Ltd.	3
Prodorite Ltd.	56
Pye, W. G., & Co. Ltd.	507
Q.V.F. Ltd.	15
Rapid Magnetic Machines Ltd.	August
Redler Conveyors Ltd.	31
Rhodes, B., & Son Ltd.	51
Rhodes, Brydon & Youatt Ltd.	42
Riley, A. J., & Sons Ltd.	20
Rotameter Manufacturing Co. Ltd.	August
Royston, George, & Son Ltd.	June
Sandvik Steel Band Conveyors Ltd.	August
Saunders Valve Co. Ltd.	39
Scott, George, & Son (London) Ltd.	60
Sharples Centrifuges Ltd.	515
Shaw-Petrie Ltd.	40
Shell Chemical Co. Ltd.	Cover 3
Simmons & Hawker Ltd.	August
Simon-Carves Ltd.	July
Simon Engineering (Midlands) Ltd.	July
Spence, Peter, & Sons Ltd.	511
Spencer-Bonecourt-Clarkson Ltd.	July
St. Helens Cable & Rubber Co. Ltd.	59
Stainless Steel Vessels	August
Stockdale Engineering Ltd.	10
Stone, J., & Co. (Deptford) Ltd.	August
Sturtevant Engineering Co. Ltd.	August
Tanks & Linings Ltd.	18
Taylor Rustless Fittings Co. Ltd., The	61
Teddington Aircraft Controls Ltd.	21
Thermal Syndicate Ltd., The	60
Thompson (Dudley), John, Ltd.	June
Turner & Brown Ltd.	58
Unistrut Division of Sankey-Sheldon Ltd.	August
Vacu-Blast Ltd.	48
Vickerys Ltd.	August
Vokes Genspring Ltd.	12
Walker, James, & Co. Ltd.	August
Walker, P. M., & Co. (Halifax) Ltd.	12
Ward, Thos. W., Ltd.	August
Watson, H. T., & Co. Ltd.	521
Welding Technical Services Ltd.	49
Wellington Tube Works Ltd.	505
Whittaker, Hall & Co. Ltd.	61
Widnes Foundry & Engineering Co. Ltd.	28
Williams & James (Engineers) Ltd.	59
Wolf Electric Tools Ltd.	47
Worthington-Simpson Ltd.	August
Wynn (Valves) Ltd.	53
Young, A. C., & Co. Ltd.	50
Zwicky Ltd.	52

Proprietors and Publishers, Heywood & Co. Ltd., Drury House, Russell Street, Drury Lane, London, W.C.2. Tel.: TEMple 3422. Subscription Rates, including postage for one year, £1 10s. U.K. ($6 U.S.A. and Canada); single copies 2s. 6d. net (by post 3s.). Printed in Great Britain by The Sidney Press Ltd., Sidney Road, Bedford, September, 1957. Communications relating either to Editorial or Advertising should be addressed to British Chemical Engineering, Drury House, Russell Street, Drury Lane, London, W.C.2.